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CONTENTS

J. BROWN. The Nature of Set-to-Learn and of Intra-Material Interference in Immediate Memory - - 141

I. M. L. HUNTER. Tactile-Kinaesthetic Perception of Straightness in Blind and Sighted Humans - - 149

HARRY KAY. The Effects of Position in a Display upon Problem Solving - - - - - - - 155

HANNAH STEINBERG. Selective Effects of an Anaesthetic Drug on Cognitive Behaviour - - - 170

WALTER M. GORDON and D. E. BERLYNE. Drive-Level and Flexibility in Paired-Associate Nonsense-Syllable Learning - - - - - 181

Book Reviews - - - - - - - - - 186

Index of Authors - - - - - - - - 188

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CONTENTS

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CONTENTS

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U. T. PLACE. The concept of heed.

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THE QUARTERLY JOURNAL OF
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Vol. VI 1954 Part 4

THE NATURE OF SET-TO-LEARN AND OF INTRA-MATERIAL INTERFERENCE IN IMMEDIATE MEMORY

BY

J. BROWN

From the Psychological Laboratory, University of Cambridge.

The influence of set on learning has previously been demonstrated under conditions where set could affect either the selection of stimuli in perception or their subsequent rehearsal. With both these possibilities excluded, set was still found to have a strong influence on learning: this suggests that set can somehow facilitate the formation of the memory trace when a stimulus is perceived.

Two forms of intra-material interference were shown to occur during the recall period. The attempt to recall one part of the material presented interfered with, and was itself impaired by, the attempt to retain the part yet to be recalled.

I

Introduction

A number of experiments have shown that "anticipation" or "set" can have important effects on learning (e.g. Postman and Jenkins, 1948); yet the ways in which these effects may be produced have not been separated. There are several *indirect* ways in which the set of the subject, at the time stimuli are presented, may influence what learning occurs. What is learned must first be perceived, and which stimuli or aspects of stimuli are perceived is largely a function of set. Set may also affect learning through determining which stimuli or aspects of stimuli are rehearsed and organized subsequent to their presentation. But it is also possible that set *directly* affects learning. Set-to-learn may somehow strengthen the memory trace set up at the time of perception. It is this possibility which is studied in the first experiment.

Intra-material interference is sometimes ascribed to pro-active and retro-active inhibition, terms which are only names for the phenomena to be explained. The problem is the *nature* of this interference. In the immediate memory situation, it has a number of possible sources. Kay and Poulton (1951) obtained evidence which suggested that active retention of earlier items is a source of interference with the learning of later items. The present experiments carry the analysis of intra-material interference in immediate memory a step further by demonstrating that recall of items recalled first interferes with the retention of items yet to be recalled; and, conversely, active retention of items yet to be recalled interferes with the recall of earlier items.

II

Method

In the first experiment, two series of items, one of arrows (the A series) and one of numbers (the N series), were presented to the subject in each trial. The subject then attempted to recall either (i) the A series only, or (ii) the N series only, or (iii) first series A and then series N, or (iv) first series N and then series A. He was told which of these alternatives was required either just before or just after the presentation of the series, so that recall requirements were either known (k) or ambiguous (a) during presentation. In all, therefore, eight conditions were used, which can be symbolized A(a), A(k), N(a), N(k), AN(a), AN(k), NA(a), NA(k). Thus A(a) denotes that only series A was to be recalled but that the subject did not know this until after the two series had been presented; NA(k) denotes that series N was to be recalled first and then series A, the subject being told this before the presentation of the series; and so on. Each subject received trials under all conditions: the conditions were given in random order.

The effects of different kinds of set on learning either or both series is shown by the level or recall under each (k) condition as compared with the corresponding (a) condition. For example, comparison of A(k) with A(a) reveals whether set to learn only the A series increases the recall of this series, since only under the former condition was the subject aware during presentation that the N series would not have to be recalled. Perception of both series was ensured under every condition by requiring the subject to make a differential response to every item as it was presented. Rehearsal of earlier items during the presentation of later items was minimized by a fast rate of presentation.

The effect of interpolated recall of N on the recall of A is obtained by comparing the recall of A under conditions A(a) and NA(a). The effect of concurrent retention of N on the recall of A is obtained by comparing conditions A(a) and AN(a). Similarly, the effects of interpolated recall on concurrent retention of A on the recall of N are obtained by comparing conditions N(a) and AN(a) and conditions N(a) and NA(a) respectively. Only (a) conditions can be used for these comparisons, otherwise differential learning during presentation may affect the results.

The second experiment was similar, except that only (a) conditions were used and the two series of items were numbers N and letters L instead of numbers and arrows. Thus the conditions in this experiment can be symbolized N(a), L(a), NL(a) and LN(a).

III

Apparatus

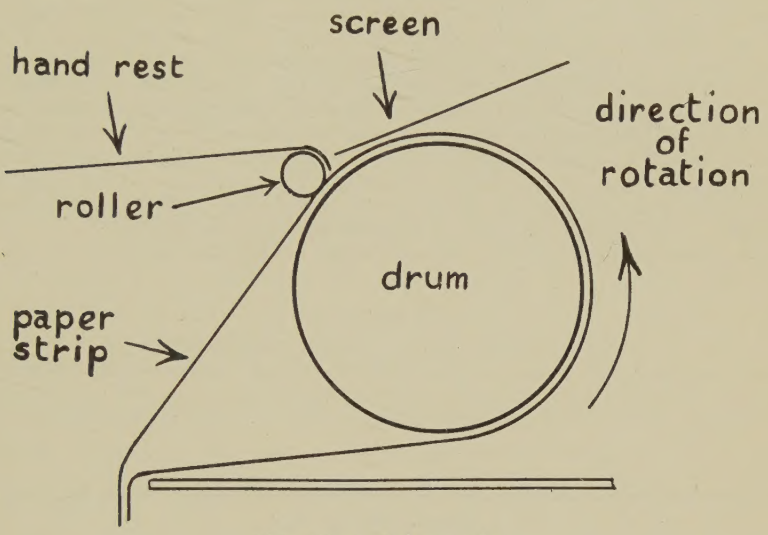
The apparatus may be of some general interest, as it has provided a simple and flexible way of presenting stimuli and of recording hand responses in a variety of experiments. Stimuli are recorded on the left-hand side of a strip of paper and are carried by a rotating horizontal drum behind a screen containing a viewing slit (Figure 1A). The drum is driven by an electric motor controlled by a switch. On the right, the screen has a reaction slit in which the subject can draw lines to right or left of varying amplitude in response to signals appearing in the viewing window: because the paper is moving, the slope of the lines indicate whether they were drawn in the correct direction (Figure 1B and 1C). If each subject uses a different coloured biro pen or pencil, six or more subjects can be tested using the same paper strip. Scoring is particularly easy, since stimuli and responses appear side by side. The rate of presentation is varied either by altering the spatial distance between successive stimuli or by changing the speed of rotation of the drum. The width of the viewing slit can be altered by a shutter.

In the first experiment, the paper speed was 18 mm./sec. and the interval between successive groups of stimuli 14 mm.: in the second the corresponding values were

9 mm./sec. and 7 mm. Thus in both experiments one group of stimuli was presented every 0·78 sec. The width of the viewing slit was 4·5 mm., just greater than the height of the stimuli.

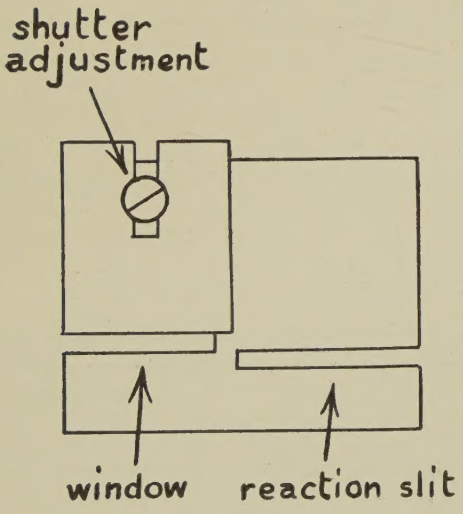
APPARATUS

FIGURE 1A



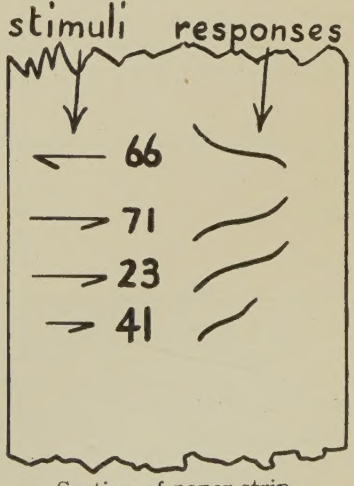
Side View of Apparatus

FIGURE 1B



Screen

FIGURE 1C



Section of paper strip

IV

FIRST EXPERIMENT

Details of method.

In each trial, four groups of items were presented to the subject at intervals of 0·78 sec. Each group consisted of a pair of digits and a four-choice arrow; thus two series of items were presented concurrently. Each arrow was long or short and pointed right or left

(Figure 1C). As each group appeared, the subject drew a line in the reaction slit in the direction shown by the arrow and of roughly appropriate length. At the same time, he read out the pair of numbers, which were checked by the experimenter against a key. The stimuli were randomly selected for each trial, except that very easy sequences were eliminated.

Six naval subjects were tested. Each was given four series of eight trials. The eight conditions were given in a different random order in each series and different for each subject, each condition appearing once in each series. The stimuli for each series were recorded on separate paper strips, so that there was a short interval betwen series during which the next strip was inserted into the apparatus. Each strip contained stimuli for one extra trial, for the occasional instances when the subject misunderstood or forgot the recall instructions, thus enabling the condition in question to be unobtrusively repeated.

Under (k) conditions, before switching on the motor, the experimenter told the subject the recall requirements, for example, "Numbers then arrows." Under (a) conditions, this information was given at the moment the motor was switched off at the end of the presentation. The subject recorded his recall attempts on paper.

Subjects were given a practice day one week before the test day.

TABLE I

RECALL SCORES FOR NUMBERS (EXPERIMENT 1)

$N(k) = D_1R_1$	$N(a) = D_2R_1$	$NA(k) = D_1R_2$	$NA(a) = D_2R_2$	$AN(k) = D_1R_3$	$AN(a) = D_2R_3$
150	98	118	70	86	74

(Scores out of 192)

TABLE II

ANALYSIS OF VARIANCE FOR TABLE I

Source	*S.O.S.*	*D.F.*	*M.S.*	*V.R.*	*Significance*
Between S's (subjects)	344	5	68·5	4·87	$P < 0.05$
" R's	273	2	136·5	9·68	< 0.01
" D's	284	1	284·0	20·14	< 0.001
S × R interaction	271	10	27·1	1·92	not significant
S × D "	103	5	20·6	1·46	not significant
R × D "	145	2	72·5	5·14	< 0.02
Residual	141	10	14·1	—	
Total	1561	35			

Comparison	*Difference*	*S.E.*	*"t" (with 10 D.F.)*	*Significance*
N(k) — N(a)	52	13·00	4·000	$P < 0.1$ if $t > 1.812$
NA(k) — NA(a)	48		3·692	$P < 0.05$ if $t > 2.228$
AN(k) — AN(a)	12		0·923	$P < 0.01$ if $t > 3.169$
N(a) — AN(a)	24		1·846	
N(a) — NA(a)	28		2·154	

Results.

Each number or arrow was scored correct only if placed by the subject in the correct position in the sequence. Table I shows the pooled scores for the recall of numbers for the group as a whole. Table II shows a three-way analysis of variance of the results summarized in Table I. The D classification refers to whether the

recall requirements were known during learning, i.e. (k) versus (a) and the R classification to whether the series concerned (in this case numbers) was recalled by itself or before or after the recall of the other series, i.e. N versus NA versus AN. The same trends in the comparisons were found on the practice day. For two of the three comparisons, recall is considerably higher under the (k) than under the (a) condition ($P < 0{\cdot}01$), and in the third comparison the difference, though smaller, is in the same direction.

Comparison of conditions N(a) with conditions AN(a) and NA(a) shows the effects of interpolated recall and concurrent retention respectively. The expected trends are present, but they are significant (at the $P = 0{\cdot}05$ level) only if their significance is measured by a one-tail test (in which case the values shown in Table II of P for different values of "t" should be halved). A one-tail test can be justified on the grounds that the hypothesis of interference predicts the direction of any differences. However, since no similar trends were obtained in the recall of arrows (see Table III), the second experiment was performed in order to obtain more convincing evidence that these forms of interference can play an important role in immediate memory. The significant interaction in Table II ($R \times D$) is that between the recall requirements and whether these were known during presentation.

Table III shows the recall scores for arrows. A three-way analysis of variance revealed no significant differences between conditions. The trends in the (k) versus (a) comparisons are similar to those in the comparable comparisons in the recall of numbers and they were also obtained on the practice day. With arrows, however, the difference between NA(k) and NA(a) is not merely smaller than the other two differences, but is actually negative. Thus (k) seems to favour mainly the series of items to be recalled first.

TABLE III

Recall Scores for Arrows (Experiment 1)

A(R)	A(a)	AN(R)	AN(a)	NA(R)	NA(a)
50	36	49	37	47	38

(Scores out of 96)

V

Second Experiment

Details of method.

The second experiment differed from the first chiefly in employing only (a) conditions. Other differences were as follows. The two series were presented successively instead of concurrently. In each trial, instead of the number-arrow groups, two pairs of number digits followed by a single digit were presented and then two pairs of letters (*consonants*) followed by a single letter. These six groups of stimuli appeared at intervals of 0·78 sec. Each subject received three series of eight trials, each condition occurring twice in each series. (The order of conditions was randomized as in the first experiment.) A fresh group of twelve naval subjects was used. They were given a practice day one week before the test day.

Results.

Table IV shows the recall scores for letters and numbers under each of the conditions for the group as a whole. Table V gives a three-way analysis of the results summarized in Table IV. The R classification concerns the conditions of recall, as in Table II: the B classification refers to whether the recall of letters or numbers

is under consideration. In this experiment, the effects of both interpolated recall (comparison 2, Table V) and concurrent retention (comparison 1) are significant ($P < 0{\cdot}01$ and $P < 0{\cdot}02$ respectively). Comparisons 3–6 show the effects of these interferences when the recall of numbers and of letters are considered separately.

TABLE IV

RECALL SCORES (EXPERIMENT 2)

Recall of numbers ..	N(a) = B_1R_1 176	NL(a) = B_1R_2 150	LN(a) = B_1R_3 142
Recall of letters ..	L(a) = B_2R_1 267	LN(a) = B_2R_2 230	NL(a) = B_2R_3 141

(Scores out of 360)

TABLE V

ANALYSIS OF VARIANCE FOR TABLE IV

Source	*S.O.S.*	*D.F.*	*M.S.*	*V.R.*	*Significance*
Between S's (subjects) ..	458	11	41·6	3·25	
" R's ..	527	2	263·5	20·58	$P < 0{\cdot}01$
" B's ..	393	1	393·0	30·70	
B × R interaction ..	212	2	106·0	8·28	
B × S interaction ..	199	11	18·1	1·41	not significant
R × S interaction ..	233	22	10·6	0·83	
Residual	281	22	12·8	—	
Total	2303	71			

	Comparison	*Difference*	*S.E.*	*"t" (with 22 D.F)*	*Significance*
1	$R_1 - R_2$	63	24·78	2·542	$P<0{\cdot}10$ if $t>1{\cdot}717$
2	$R_1 - R_3$	160		6·457	$P<0{\cdot}05$ if $t>2{\cdot}074$
3	N(a) — NL(a)	26		1·483	$P<0{\cdot}02$ if $t>2{\cdot}508$
4	L(a) — LN(a)	37	17·53	2·111	$P<0{\cdot}01$ if $t>2{\cdot}819$
5	N(a) — LN(a)	34		1·939	
6	L(a) — NL(a)	126		7·188	

It will be seen from Table V that the interaction between B (which recall series) and R (which recall condition) is significant. This is traceable to a smaller effect from the interpolated recall of letters on the recall of numbers than from numbers on the recall of letters.

VI

DISCUSSION

The nature of the effect of set of learning.

Recall tends to be considerably higher under (k) conditions (recall instructions given before presentation) than under corresponding (a) conditions (recall instructions given after presentation). Before this is taken as showing that the "set" of the subject can directly affect learning, the possible influence of other factors has to be considered. The discussion will proceed initially in relation to the largest difference between (k) and (a) conditions, namely, that between N(a) and (N(k): recall was over

50 per cent. higher under the latter condition. Since responses were required to both the arrows and the numbers as they were presented and errors in reponse were very rare, the difference cannot be attributed to the subject ignoring the arrows in the sense of failing to perceive them. Some of the difference may be due to selective rehearsal of the numbers during presentation, since it is impossible to be certain that rehearsal was prevented completely. However, it is unlikely that much of the difference can be so explained. Presentation was at the highest rate at which the subjects could make responses to the items without error: in the language of "Information Theory," rate of gain of information was near the maximum (the rate was actually just under twelve bits per second). The effect of a further factor must also be taken into account. An inevitable feature of the experiment was that recall instructions intervened before recall under (a) conditions but not under (k) conditions. It is therefore probable that this interpolation of instructions before recall contributed to the lower recall under N(a). But it is unlikely to have contributed much since, firstly, recall instructions were brief, viz. "numbers only," and constituted a much smaller interpolation than the recall of arrows before numbers under AN(a); secondly, despite this, the difference in the recall of numbers under N(a) and N(k) is over twice as large as the difference under N(a) and AN(a) (see Table I). It therefore seems reasonable to conclude that other factors can only account for a small part of the difference in recall under N(k) and N(a), most of which can be attributed to a direct effect of set to learn N only on the strength of the traces set up by perception.

The interpretation of other (k) versus (a) comparisons will now be considered briefly. Recall of numbers was significantly higher under NA(k) than NA(a), the difference being almost as large as that between N(k) and N(a): but the recall of arrows was *lower* under NA(k) than under AN(a). Thus there is no evidence here that set to recall one series first resulted in learning being so organized that both series were better recalled. Although differences in the recall of arrows under (k) and (a) conditions were not significant, there was a consistent trend in favour of (k) on both practice and test days, except where numbers were recalled first. It seems probable, therefore, that set can affect the learning of non-verbal material (arrows) as well as of verbal material (numbers).

The results imply that there is some process by which the retention of a limited quantity of material can be facilitated, not depending on the strengthening of learning through rehearsal. It would be plausible to suppose that the retention of any stimulus which has novelty value tends to be facilitated in this way. This would provide an explanation of von Restorff's finding (quoted in Woodworth, 1938) that the single item in a list differing from the rest is better remembered.

Intra-material interference.

The experiments clearly demonstrate two forms of interference during the recall period, namely from the interpolated recall of items recalled first and from the concurrent retention of items yet to be recalled.

It might be suggested that the effect of interpolated recall is due simply to the consequent delay before the subject can attempt to recall the remaining items. However, in a previous experiment (unpublished) no drop in recall was produced if subjects were merely required to delay recall for several seconds. An assumption which would explain both interferences is that retention in immediate memory is an active not a passive process (cf. Kay and Poulton, 1951), since recall during the active retention of later items would produce mutual interference.

A peculiar feature of the first experiment is that there is no sign that these interferences lower the recall of arrows. Thus there seems to be a difference between the

susceptibility of verbal and non-verbal material to their influence. A partial explanation of this difference may be that verbal material is easier to rehearse effectively: for interference with rehearsal would then produce a greater relative effect on the recall of numbers. Both interferences, with verbal materials, were sufficiently large to suggest that they are important factors in limiting the memory span. They will also help to determine the serial position effect. In the recall of a series of items, the early items will be subject mainly to interference from concurrent retention and later items mainly to interference from interpolated recall. According to which interference is stronger, the earlier or the later items will be favoured in recall: the actual serial position effect will also depend on any other forms of intra-material interference present.

My thanks are due to Dr. A. Carpenter for much helpful discussion and to Professor G. C. Drew who read the manuscript. I am also indebted to the Royal Navy for supplying the subjects.

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TACTILE-KINAESTHETIC PERCEPTION OF STRAIGHTNESS IN BLIND AND SIGHTED HUMANS

BY

IAN M. L. HUNTER

(*Psychology Department, University of Edinburgh*)

A comparison is made between the tactile-kinaesthetic perception of straightness in twenty blind and twenty sighted subjects. Both types of subject are found to perceive a "plus curved" edge as straight, but this curve is significantly less for the blind than for the sighted, i.e. the blind subjects' judgments correspond more closely to the objective straight. Furthermore, the blind, both as individuals and as a group, are significantly finer in their judgments and more consistent. These results are thought to be explained in terms of the more highly developed organisation of the blind's tactile-kinaesthetic perception.

I

Introduction

The tactile-kinaesthetic perception of straightness in sighted adults was investigated independently by Rubin (1936) and Blumenfeld (1937). Rubin's eight blindfolded subjects were presented, in the frontal-parallel plane, with a horizontal steel ruler which could either be straight or curved by varying amounts concavely or convexly to the subject. The subject's task was to slide his finger-tips to and fro along the upper edge of this ruler and judge whether it was "plus curved" (i.e. its middle bent away from him), "minus curved" (i.e. its middle bent towards him), or "straight." Each subject was given repeated presentations of the ruler variously curved and the average value calculated of those curves judged "straight." There were two experimental conditions depending on whether or not the upper arm was mobile. In the short-arm condition, only the forearm was moved, the elbow acting as centre; in the long-arm condition, the whole outstretched arm was moved, the shoulder now being centre. The main conclusion was that the edge perceived as straight was, in reality, plus curved. Furthermore, though this plus curve was greater under the short-arm than under the long-arm condition, it was always less curved than the arc traced by the fingertips with the outstretched arm (or forearm) as radius and the shoulder (or elbow) as centre. These findings, as Rubin observed, could be interpreted in two ways. Assuming the complete correspondence of perceived and objective straightness, they demonstrated an illusion. Assuming that the curve judged straight should be the arc described by the moving member, then they demonstrated a constancy effect, or what Thouless (1931) might have called a phenomenal regression to objective straightness. In his study, Blumenfeld used, in addition to the horizontal ruler, a device whereby subjects were presented with three vertical rods in the horizontal frontal-parallel position and were required to place the middle one in a straight line with the two outer ones. His investigation, although more fragmentary than Rubin's, arrived at essentially the same conclusions.

Using his technique of the three vertical rods, Blumenfeld compared the performances of sighted adults with those of four blind adults. Three years later, Crewdson and Zangwill (1940) compared one blind with three sighted adults on a replica of Rubin's horizontal ruler. The results of both studies indicated that (1) the differential threshold between straightness and curvature was lower for the blind than for the sighted; and (2) while, in both types of subject, perceived straightness was given by a plus curve, this curve was greater for the blind than for the sighted. However, because of the small number of subjects employed and the considerable individual differences found, these findings were, at best, merely suggestive. It is

the purpose of the experiment reported below to determine whether these two tentative conclusions are confirmed when larger numbers of blind and sighted are compared.

II

Experiment

Subjects

Taking part were twenty blind and twenty sighted subjects, matched for age and intelligence as nearly as possible. The blind aged from 12 yrs. 6 mos. to 18 yrs. 11 mos. with a mean age of 15 yrs. 8 mos. and a mean I.Q. of 113. The sighted aged from 12 yrs. 6 mos. to 18 yrs. 7 mos. with a mean of 15 yrs. 5 mos. and a mean I.Q. of 111. Although seven of the blind subjects were sensitive to light, not one of them had any object vision. Five were congenitally blind, two had become blind in the first year of life, three in the second year, three in the third, one in the fourth, two in the sixth, one in the seventh, one in the eighth, and two in the tenth year.

Some indication of the histories of the blind subjects is given below, the following five items of information being supplied for each. Sex, whether male (M) or female (F). Age at testing, given in years and months. The present state of vision with regard to which every subject fell into one of only two categories, i.e. completely blind (total) and sensitive to light stimulation (light). The cause and age of onset of blindness. Lastly, the age at which the child's present state of blindness was most probably reached: it is to be stressed that the age given is often an approximate one guessed at in the absence of reliable data.

1.	M.	14·10.	Light.	Keratitis at 1 yr.	1 yr.
2.	M.	12·08.	Total.	Glioma at 2 yrs.	2 yrs. 6 mos.
3.	F.	13·06.	Total.	Glioma at 2 yrs.	4 yrs.
4.	F.	13·11.	Light.	Congenital cataract.	From birth.
5.	F.	13·02.	Total.	Congenital cataract.	From birth.
6.	F.	12·11.	Light.	Congenital familial.	From birth.
7.	F.	15·03.	Total.	Iridocyclitis at 1 yr.	1 yr.
8.	F.	16·10.	Total.	Uveitis at 3 yrs.	3 yrs.
9.	F.	13·10.	Light.	Choroiditis at 7 yrs.	7 yrs.
10.	F.	15·03.	Total.	Keratitis at 2 yrs.	2 yrs.
11.	F.	16·04.	Light.	Burning accident at 6 yrs.	6 yrs.
12.	F.	17·06.	Total.	Choroido-retinitis at 7 yrs.	10 yrs.
13.	F.	17·04.	Total.	Uveitis at 2 yrs.	6 yrs.
14.	F.	18·01.	Total.	Optic atrophy after brain operation at 10 yrs.	10 yrs.
15.	F.	17·05.	Total.	Ophthalmia neonatorum.	From birth.
16.	F.	17·00.	Total.	Glioma at 1 yr.	3 yrs.
17.	F.	18·11.	Total.	Ophthalmia neonatorum.	From birth.
18.	M.	12·06.	Light.	Uveitis at 3 yrs.	3 yrs.
19.	M.	15·02.	Light.	Congenital cataract with deterioration.	8 yrs.
20.	F.	15·08.	Total.	Glioma at 1 yr. 6 mos.	2 yrs.

Apparatus

A flexible steel ruler, 205 mm. long and 0·5 mm. thick, was clamped at both ends and in the middle. The end clamps were fixed to a wooden board so that the ruler was held horizontal with its broad surface vertical and its 0·5 mm. edge uppermost. It was along this edge that the subjects were to move their fingertips. The middle clamp, placed so as not to interfere with the subjects' movements, could be moved, by means of a micrometer screw, either towards the subject (giving a minus curve) or away from him (giving a plus curve). A millimeter scale showed the distance by which the middle of the ruler was displaced from the straight.

Procedure

For every subject, whether blind or sighted and blindfolded, the procedure was identical. He was seated at a table, with his elbow placed in a rest on the table's near edge, and instructed to keep his upper arm stationary throughout the experiment. Only the short-arm condition was used. The apparatus lay before him, in the frontal-parallel plane, in such a position that its middle was directly in front of his elbow, and at such a

distance that he could run his fingertips comfortably along the ruler's length. He was then given a series of trials on which the ruler was variously curved and on which he was required to judge whether it was "straight," or whether the middle was "bent away" or "bent towards." On any one of those trials the ruler might be straight or bent with its middle displaced, positively or negatively, by a distance which was a multiple of 2 mm. These curves were presented in randomized order and each subject had a total of about fifty trials. With this type of procedure (i.e. the psychophysical method of single stimuli), each subject should, ideally, have the same number of trials on each of the same stimuli. But since there were large individual differences in the particular curves consistently judged as bent and since the number of trials which could be given each subject was limited, it was recognized that the ideal procedure would be wasteful in many cases. A compromise was, therefore, adopted in which the range of curves varied from subject to subject as required, but was always such that the two extreme curves were consistently judged as, respectively, "bent away" and "bent towards." This meant that the number of trials involving a particular curve varied from subject to subject, e.g. if he required a range of −4 mm. to +4 mm. he would make ten judgments on each of five curves (−4, −2, 0, +2, and +4), but if he required a range of −8 mm. to +10 mm., he would make five judgments on each of ten curves. Throughout, no restriction was placed on the number of fingers used by the subject nor on the speed or frequency with which they traversed the length of the ruler. Half of the subjects in each group used the left hand and half used the right.

Results

It may be discovered whether the performance of the blind group differed from that of the sighted by comparing the values of all the curves judged "straight" by all the subjects in each group. Table I shows this comparison and enables two statements to be made. First, while perceived straightness corresponded to a plus curve in both groups, this curve was significantly greater for the sighted than for the blind, i.e. the blind's tactile-kinaesthetic perception of straightness corresponded more closely to objective straightness. Second, the judgments of the sighted were significantly more variable than those of the blind.

TABLE I

	No. "straight" judgments	*Mean*	*Standard deviation*
Blind Group ..	305	+1·44	3·03
Sighted Group ..	407	+2·37	4·93
t ..		3·10	9·05
p ..		<·01	<·001

The second statement must now be elaborated since the greater variability of the sighted could have been due to three different conditions. (1) They could have had a higher differential threshold between straight and curved. (2) They could have differed more among themselves regarding the mean values of their "straight" judgments. (3) As individuals, they could have been less consistent in their judgments on the same curve. Detecting the presence of the first condition involves some measure of the scatter of the individual's judgments. Such a measure is the "range," defined as the number of curves intervening between those which were consistently judged as either "bent away" or "bent towards." The mean range of the blind subjects is found to have been 5·6 curves with a standard deviation of 1·07; the sighted had a mean range of 7·2 curves and a standard deviation of 2·36. The difference between the two means and the difference between the two standard deviations are both significant at the ·01 level of probability. Whether the second

condition was present can be determined by calculating the mean value of the curves judged "straight" by each individual subject. When this is done the standard deviations of these mean values is 1·15 for the blind and 2·71 for the sighted. The difference between the two is significant at the ·005 level. The presence of the third condition may be detected by calculating, for each group, the proportion of curves on which all three judgments were passed by the same individual. For the blind, this proportion was ·046 and, for the sighted, was ·201. These proportions are significantly different beyond the ·001 level. To conclude: as contrasted with the blind subject, the sighted subject was less consistent in his judgments, had a wider scatter of judgments, and differed more from his fellows with regard to the extent of this scatter and its mean value. In other words, the blind, both as individuals and as a group, were finer in their judgments and more consistent.

The present experiment yields evidence not only on the effect of visual experience (or the lack of it) on the tactile-kinaesthetic perception of straightness, but also on the effect of chronological age. The subjects, blind and sighted together, may be split into three age groups, i.e. fifteen aged 12 yrs. 6 mos. to 13 yrs. 11 mos. (Age Group I), thirteen aged 14 yrs. 0 mos. (Age group II) to 16 yrs. 11 mos., and twelve aged 17 yrs. 0 mos. to 18 yrs. 11 mos. (Age Group III). The performances of Age Group I and Age Group III (the mean ages of which are 13 yrs. 1 mos. and 17 yrs. 10 mos., respectively) are compared in Table II. This table shows that perception

TABLE II

	No. "straight" judgments	*Mean*	*Standard deviation*
Age Group I ..	309	+2·01	4·96
Age Group III ..	243	+1·79	3·83
t ..		·59	4·35
p ..		>·5	<·001

was no more objective in the one group than in the other, but that judgments were significantly less variable in the older group than in the younger.

No consistent difference was found between those subjects who used their left hand and those who used their right.

III

Discussion

In interpreting the above results, there can be little doubt that a practice effect is responsible for the smaller variability of judgment shown by the blind as opposed to the sighted and by the older subjects as opposed to the younger. The postulation of such an effect rests on three reasonable suppositions: that perceptual judgments of any sort become less variable with practice; that practice in tactile-kinaesthetic perceiving increases with age; and that, because of the greater part it plays in their reading, writing and perception of the world generally, the blind have "more" experience of tactile-kinaesthetic judgment than the sighted. The third supposition might be better expressed by saying that, because they are obliged to depend more exclusively upon it, the blind have a more highly organised tactile-kinaesthetic perceptual system in the same way as the taste of the tea blender and the hearing of the musician is more highly developed than is ordinarily so.

The greater objectivity of the blind's straightness judgments is open to more complex interpretation. At least logically, two possibilities exist. Perhaps the more highly developed the visual perception, the less objective is the judgment of tactile-kinaesthetic straightness. Or it could be that this judgment becomes more objective with the greater development of tactile-kinaesthetic perception. The former possibility seems the less plausible. Rubin has shown, admittedly, that vision may influence tactile-kinaesthetic perception. When a subject explores an edge with his fingers and simultaneously looks at it, the plus curve is no longer judged straight but tactile-kinaesthetic judgment is brought into line with the dominant visual judgment; the edge which "looks" straight also "feels" straight. Furthermore, Rubin reports that, where a blindfolded subject has a knowledge of the objective situation and employs strong visual imagery, his judgments may be the same as those given while vision is actually present. But where a sighted subject is blindfolded it is difficult to imagine just how his superior visual organisation could operate to make subjective straightness correspond more closely to the arc traversed by the fingertips with the elbow as centre. If anything, it ought to make judgment more objective. The second possibility mentioned above seems to fit the facts more readily. However, the growth of tactile-kinaesthetic perception cannot be accepted as the explanation until the lack of difference between Age Groups I and III has been satisfactorily accounted for.

With both blind and sighted subjects, practice between the ages of thirteen and eighteen years has little effect on the objectivity of straightness judgments. This could be explained if the effects of tactile-kinaesthetic practice were restricted to a certain developmental stage or, alternatively, were limited in amount. This would mean, in the one case, that whatever effect practice has on objectivity is, unlike its effect on variability, complete before the age of thirteen. Otherwise expressed, practice is limited to a critical period of development so that, by thirteen years, judgments of straightness, and perhaps other aspects of space perception besides, are "set" to be influenced thereafter only by complex processes of instruction and reasoning. Were this so, persons blinded after the critical period would never give straightness judgments comparable in objectivity to those of persons blinded before the critical period. Unless, that is, they came to understand that the moving arm described an arc rather than a straight line and, by reasoning, compensated for this. The alternative explanation is in terms of an absolute limit to the amount of practice which is effective. The blind might not improve after thirteen because they had already reached the limits of practice. The sighted, on the other hand, might have reached an artificial limit of tactile-kinaesthetic practice temporarily imposed by their use of vision. Were this so, persons blinded at any age whatever would eventually become more objective in their straightness judgments. Which, if either, of those two explanations holds is a point which must be settled on the basis of evidence not yet available. But, as regards the present discussion, the important thing is the demonstration that a reasonable explanation does exist for the results shown by the two age groups.

Perhaps, then, the most plausible explanation of the blind's greater objectivity in the tactile-kinaesthetic perception of straightness is that, as a result of greater practice, they approximate more closely to an objective judgment and, although never completely free from the distorting effect of the arm's radial movement, are less influenced by it. In harmony with this explanation is the finding of Crewdson and Zangwill that their blind subject's perception of straightness was less affected than was that of their sighted subjects by a change from the short-arm to the long-arm condition. It is likely that, had the blind subjects in this experiment all been

blind from birth, the differences between them and the sighted would have been even greater.

This experiment was conducted adjunctively to a more extensive study by Professor Drever. It was he who arranged for subjects to come to the laboratory, and I am sincerely indebted to him for letting me examine them during their visit. To be thanked for making subjects available are the headmasters of Craigmillar Park Blind School, Moray House School, and George Heriot's School. Dr. Semeonoff contributed valuable advice on the use of statistics.

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THE EFFECTS OF POSITION IN A DISPLAY UPON PROBLEM SOLVING

BY

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Sixty-four subjects, aged between 15 and 72 years were told how to carry out a problem-solving task, whose difficulty could be varied by changing the position of an index card in relation to a display and control.

The outstanding feature, particularly of the older group's performance was the repetition of the same two kinds of mistake. Their failure seemed mainly due to an inability to rid themselves of their wrong "solutions," in spite of the constant information indicating the mistake at each position. Whilst these differences between the age groups were not pronounced at the easiest task, they were at the most difficult.

It is suggested that: Firstly, the procedure of giving a subject the solution to a problem and observing how he reconciles his information with it, though only operating in a circumscribed area of problem-solving, is a genuine example of thinking, and, particularly where certain kinds of mistake can be predicted, it enables the experimenter to gain a more exact impression of what a subject is doing. Secondly, the manipulation of spatial contiguities lends itself to flexible and fairly precise measurement, and the principle might usefully be extended to other variables such as size, time intervals, colour, etc.

I

Introduction

This experiment does not fit neatly into any rigid category of learning or problem-solving. Several of the issues which are raised by this study will only be briefly indicated, and this paper will primarily attempt to give a full factual account of the proceedings, as it is felt that they could serve as a model for further experiments.

A previous study upon serial learning with human subjects (Kay, 1951) had illustrated how a task which would traditionally be defined as rote learning was anything but a mere rote recapitulation of the presented information. It was a feature of adult learning to repeat mistakes—that is, for subjects to ignore information which was continuously being given to them and to adhere to that version of an operation which they had themselves created. This repetitive tendency, expressed as an inability of an organism to unlearn what it has already learned, is a common enough phenomenon of behaviour, and this experiment sought to examine it in a task where as little emphasis as possible was being placed upon remembering.

The aims were to devise an experiment where—

(i) Subjects of different ages had to carry out a particular mental task.
(ii) The probable kinds of error could be largely predicted.
(iii) They would occur sufficiently often to provide quantitative data, so as to give some indication of the mental processes which had taken place.

Because of a previous experiment it was desirable that—

(iv) The task should impose as little stress as possible upon memory.

II

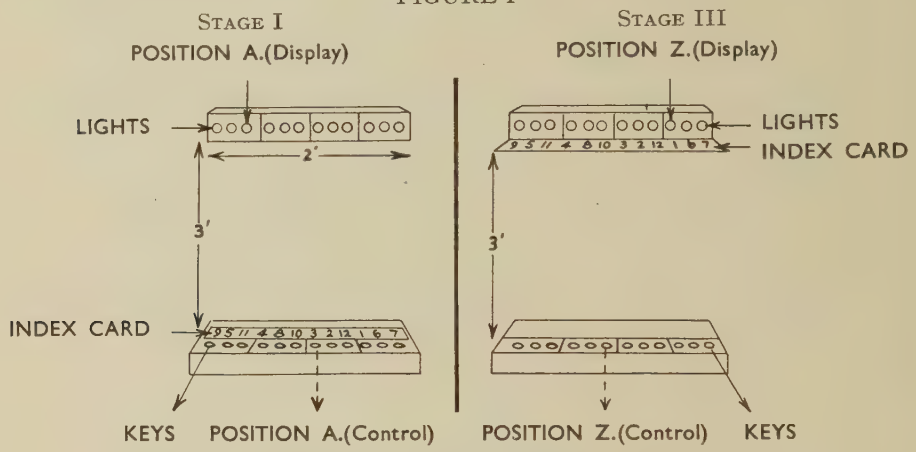
Methods and Procedure

Apparatus

The layout of the apparatus has been sketched in Figure 1. Subjects sat in front of a row of 12 Morse keys, spaced 2 inches apart. A row of lights, spaced in exactly the same way, was placed 3 feet from the keys. An index card with a randomized order of numbers upon it was positioned immediately behind the keys (*see* Figure 1, Stage I). The numerals

on the card were also spaced 2 inches apart so that they were directly in line with both the keys and lights. Markers were put after every third light and key to facilitate the numbering of spatial positions. The apparatus was constructed so that when a "correct" key was pressed it switched out the illuminated light and switched on another. When an "error" key was pressed nothing happened (so far as the subject was aware). There was then immediate knowledge of results after each response. The apparatus was wired up to a 14-pen polygraph recorder so that each key was scored separately, in addition to time intervals and correct responses. The apparatus has been described fully elsewhere (*see* Welford, 1952).

FIGURE 1



Positions of the Light-Key Apparatus at Stages I and III.

Subjects.

Sixty-four subjects took part in the experiments, 10 belonging to each of the age groups, 15–24, 25–34, 35–44, 45–54, 65–72, and 14 to the group 55–64. All subjects in the groups 15–64 were employed in one of two departments in the York factory of Messrs. Rowntree & Co. The group aged 65–72 were pensioners from the factory, who regularly attended the Pensioners' Club on the factory premises. All subjects were volunteers and all were most co-operative and helpful.

Instructions to Subjects.

A subject was seated with the apparatus in front of him and with the index card immediately behind the keys (as in Figure 1, Stage I). After he had been shown how the apparatus worked, he was given the following typewritten instructions:—

1. Think of the lights as being numbered 1 to 12 from the left.
2. When a light comes on decide which number it is.
3. Find that number on the card.
4. The correct key to hit is the key in line with the number selected on the card.

During the reading of the instructions the experimenter occupied himself with the apparatus and tried not to hurry nor to embarrass subjects. When they indicated they had finished studying the instructions the experimenter checked with all subjects if they thought they understood them and then by demonstration and questions—ostensibly to help subjects—he ascertained whether in fact they did understand correctly. These results were scored. The first stage of the experiment began after subjects had not only satisfied themselves that they thought they knew what to do, but had also satisfied the experimenter that they could begin the task correctly.

The same typewritten instructions were retained by a subject and used throughout all stages of the experiment.

Experimental Design.

Subjects were carrying out what was essentially the same task at three different stages, using the same series of 10 lights at each. The series of 10 was given twice at each stage,

so that *each* was measuring the errors and the time taken to make 20 correct responses. (Of the 12 light positions only 10 were used: positions 2 and 11 were omitted from the series, but were used for demonstrating and checking.)

Stage I. The card was placed so that each of its numerals was immediately behind a key (*see* Figure 1, Stage I). After subjects had shown that they knew how to carry out the instructions they began this stage of the experiment.

Stage II. The card was now moved to a position mid-way between the keys and the lights. Subjects were again asked to do the task exactly as indicated on their typewritten instructions, and since all of them had done the first stage satisfactorily it was pointed out to them that this was really asking them to repeat the same procedure as for Stage I.

Stage III. The card was now moved to a position in front of the lights, so that each light had a numeral immediately in front of it. Subjects were asked to continue to carry out the same instructions.

Further stages in the experiment were carried out, but these results are not being discussed in this paper.

It should be mentioned that, though we are speaking of a series of 10 or 20 responses, each response was independent of another. However, since the same Index Card was used for all three stages it was to be expected that some incidental learning of the series might occur. One of the further stages of the experiment (not discussed here) did in fact measure this incidental learning by using a different Index Card. The amount of such learning was relatively small and was less for the older than for the younger subjects. In so far as any learning of the series would tend to lessen the difficulty of Stage III it should have decreased the discrepancies between the results of the three stages which will be discussed.

Experimental Measurements.

At each stage of the experiment there were 20 "light" positions and a subject had to make a correct response at each. Two measurements were recorded:—

1. The time in seconds.
2. The number of mistakes. These have been subdivided into:
   (*a*) *First Errors.* This limits the mistakes to the first error only at each serial position; therefore, a subject can only make 20 first errors at any one stage.
   (*b*) *Total Errors.* Every mistake made at any serial position.

The distinction aids in studying the repetition of mistakes; elsewhere the terms "errors" or "mistakes" will be used to refer to either kind of wrong response.

Explanation of Task.

From the experimental instructions which have just been given it will be observed that in order to carry them out four points had to be determined:—

A. The position of the light.
B. The number of that spatial position of the light from the left. (*Spatial position number.*)
C. The numeral on the index card corresponding to that spatial position number. (*Card numeral.*)
D. The key in line with the card numeral. (*Key position.*)

To complete each response a subject had to carry out a series of substitutions, somewhat similar to that in the Digit Symbol Test of the Wechsler-Bellevue Intelligence Scale. But whereas the Wechsler Substitutions are made with a number of symbols which are learned as quickly as possible, here the aim was for all moves to be governed by some common and simple principles. Once these were learned a subject had nothing further to retain, and the experimenter's problem was to complicate the task without changing its principles. This was achieved by varying the spatial position of the index card in relation to the display and control panels. We may illustrate this by two examples.

Let us say that in Figure 1, Stage I, the light is on at position A. This was the third light position from the left end of the display. Subjects therefore found numeral three on the card and pressed the key in line with that number. (Position A Control.)

It was known that this was a simple procedure; it was easy enough to give the light a spatial position number when there was no index card near and, at the last step, to chose the key nearest to the card numeral when the two were adjacent.

But for Stage III, though the procedure was the same, both these steps were more complicated. The index card was adjacent to the lights so that there was a tendency to associate, incorrectly, a light with its nearest numeral, whilst the numerals were some distance from the keys to which they did refer. The difficulty can be observed in the example for Figure 1, Stage III, where if the four points were correctly determined we have—

A. The light is at Position Z.
B. *Spatial Position Number* of Z is 10.
C. *Card Numerals*, 10 are found.
D. *Key Position* is in line with numerals 10 (Position Z Control).

Particular Categories of Mistake.

The changing of the position of the index card in relation to the display and control made it possible to complicate or facilitate the operation as desired. But it followed that if the difficulty was being caused by a change in spatial contiguities that certain types of mistake would predominate. If their occurrence could be measured it would allow us to be much more precise about the difficulties that had been created. This section, therefore, outlines the two kinds of mistake which were predicted to occur when the index card was moved from the control to the display. (The reader who can predict the mistakes for himself is advised to continue with the results.)

We observed (above) that to carry out the task four points had to be established: this involved a subject in making three substitutions (or transformations) of the following kind:—

(i) The *light position* (A) is transformed into a *Spatial Position Number* (B).
(ii) The *Spatial Position Number* (B) is transformed into the corresponding *Card Numeral* (C).
(iii) The *Card Numeral* (C) is aligned with the *Key Position* (D).

The predicted categories of mistakes will be discussed by referring to this procedure and using the example given for Figure 1, Stage III.

Errors Type I.

It was anticipated that these errors would be caused by a subject assuming that the card numeral immediately in front of the light indicated the spatial position number of the key. The procedure would be—

A. The light is at position Z.
C. The numeral on the card *aligned* immediately below the light is identified as the correct Card Numeral (i.e. No. 1).
D. The key whose spatial position number is that of the Card Numeral is selected. (Key No. 1.)

There are two predominant features of this mistake.

(i) The first transformation is omitted (Spatial Position Number of the light).
(ii) This may arise because the order of the transformations is changed—the procedure begins where it should end with an alignment; that is, alignment with the Key becomes alignment with the numeral on the card.

Errors Type II.

It was expected that a different type of mistake would arise through subjects alinging the light position with the card numeral immediately in front of it, as in the Type I Errors, and then striking the key in line with the numeral.

In the example of Figure 1, Stage III, this mistake would produce the following:

A. The light is at position Z.

C. The card numeral immediately in line with the light is selected (No. 1).

D. The key in line with the card numeral is selected.

This mistake carries out an alignment procedure twice, which has the effect of nullifying the use of the index card. It seems a fairly obvious mistake and it was not anticipated to be as prevalent as that of Type 1. (The experimental results were to indicate the reverse.)

A predilection for either type of error at Stage III would indicate the strength of the spatial contiguity influence and the kind of mental operations which had taken place.

Random Errors.

This category was intended to include all errors not falling into the other two, and carried no further implication than this. It was thought that it would be made up of mistakes caused by misalignments, by wrong numbering, or the occasions when a subject became so "lost" that he hit all the keys in turn until he came to the right one.

III

Results

1. *The Intepretation of Written Instructions.*

Before turning to the main body of results there is an interesting note upon how adequately subjects understood their instructions. It was essential that subjects should not be mistaken about what they had to do before beginning the experiment. Accordingly, as already mentioned, the experimenter checked with subjects after they had finished studying the instructions if they thought they could carry them out, and whether they could in fact do so. Table I gives the results.

TABLE I

Ability of Subjects to Carry Out Written Instructions

Age Group	*Percentage number of subjects in each age group who:*		
	Could carry out the instructions correctly (*i*)	*Thought they could carry them out and had interpreted them wrongly* (*ii*)	*Who could not understand what they had to do* (*iii*)
15–24 ..	60	40	0
25–34 ..	50	50	0
35–44 ..	30	50	20
45–54 ..	30	40	30
55–64 ..	28	44	28
65–72 ..	20	40	40
For all Groups ..	36·3	44·0	19·7

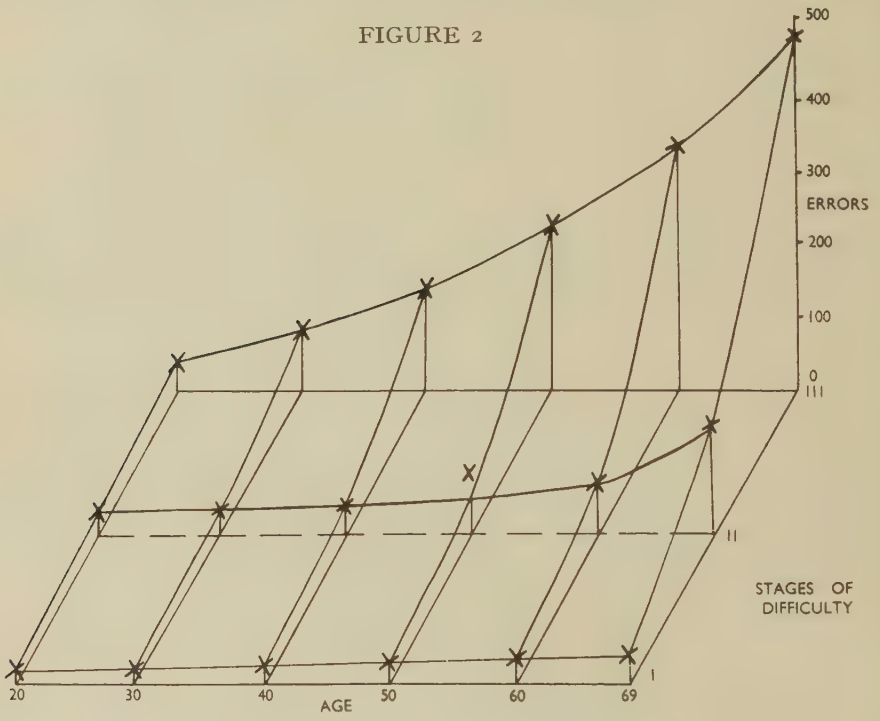
Though the instructions contained only four short simple sentences 44 per cent. of the subjects were prepared to begin the experiment saying they knew what to do when that was just what they did not know.

A second feature of Table I is that the percentage number of subjects who were able to understand the instructions decreases with age. Conversely, the number of those who knew that they did not understand them rises steadily with age (column 3).

2. *Carrying Out a Task at Three Stages of Difficulty.*

The recorded times and mistakes in performing the three stages of the experiment are set out in Table II and the errors are graphed in Figure 2.

FIGURE 2



Relation between Age, Total Errors, and Degree of Difficulty.

Subjects apparently found Stage I a fairly simple operation. They did not take long to carry it out and the number of mistakes made by all the different age groups was small. Even so the two oldest groups were making two and a half times the number of errors and taking one and a half times as long as the two youngest age groups.

At Stage II, results for all ages indicate the greater difficulty of this task over Stage I. It will be remembered that as the index card was now exactly mid-way between the display and the controls, there was nothing in the spatial layout to suggest that it should be associated with one more than the other. In so far as a subject had already followed the correct procedure at Stage I it was to be expected that he would not become confused, but in so far as the spatial contiguities no longer aided the underlying principles as they did at Stage I, it was thought that subjects would experience more difficulty.

In fact all age groups did make one and a half times to twice as many errors as they had done at Stage I, and the time scores showed a similar though slightly more marked trend. (*See* Table II.)

TABLE II

First Errors and Times at Stages I, II and III

Age Group	*Stage I*		*Stage II*		*Stage III*	
	Errors					
	Means	*S.D.*	*Means*	*S.D.*	*Means*	*S.D.*
15–25 ..	1·1	0·94	2·0	1·79	2·7	2·05
25–34 ..	1·3	0·90	2·5	2·06	4·4	1·73
35–44 ..	1·5	0·92	3·0	1·48	5·6	3·22
45–54 ..	2·1	1·30	3·7	2·96	7·6	4·17
55–64 ..	2·7	2·00	4·3	2·76	8·2	5·96
65–72 ..	2·6	1·88	4·4	3·83	12·8	5·27
	Times					
15–25 ..	56·4	9·89	70·8	17·18	84·8	35·21
25–34	54·2	4·79	71·7	18·28	111·6	43·20
35–44	62·0	29·34	85·7	31·97	137·1	84·85
45–54 ..	64·1	14·53	96·3	34·79	174·7	81·69
55–64 ..	73·7	14·39	124·8	67·44	229·3	135·61
65–72	84·7	25·96	198·7	175·90	445·3	226·71

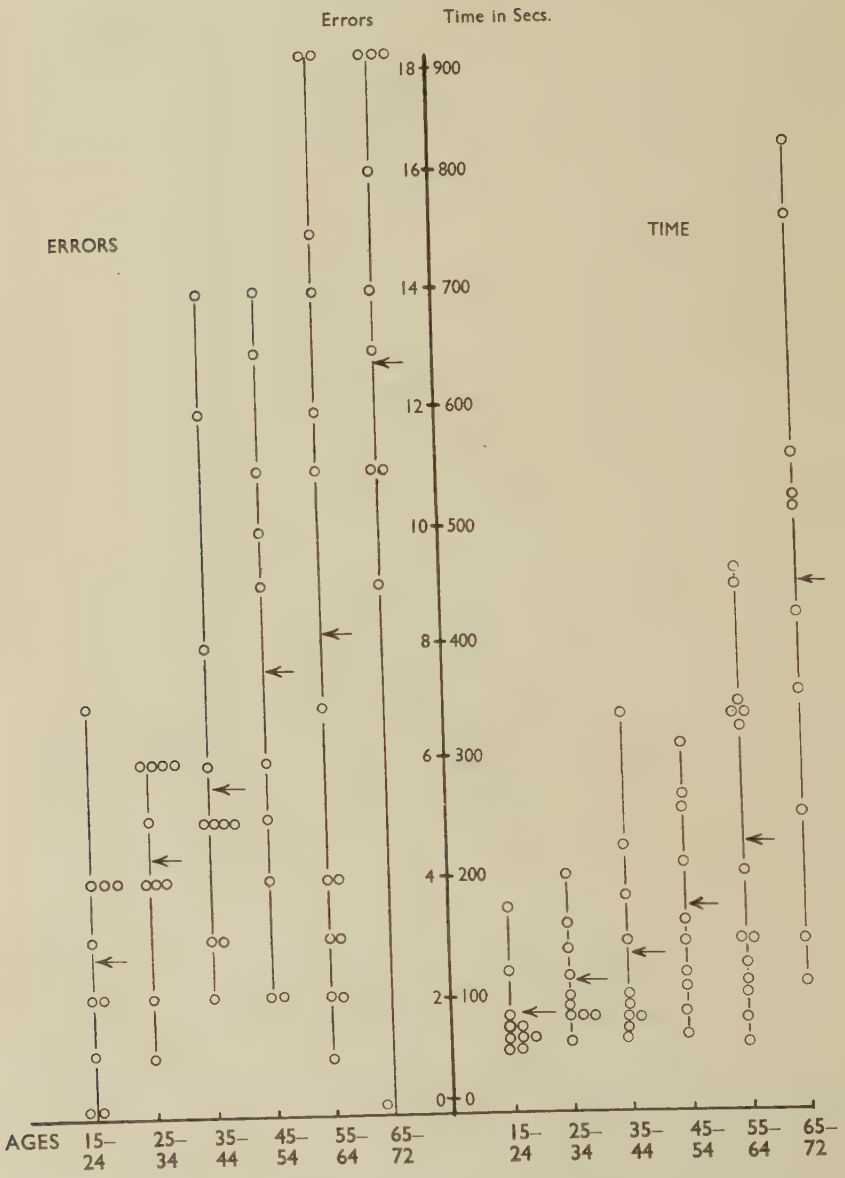
At Stage III, where the position of the index card was immediately in front of the display, the results again indicated the increased difficulty. The youngest groups were now making about three times the number of mistakes and taking approximately twice as long as at Stage I, whilst the older groups were more adversely affected. When the over 65's are compared at this stage with the under 25's they were making more than four times the errors and taking more than five times as long.

If the results at these three stages are considered as indicating the trend which takes place between different age groups as they learn to carry out a task of increasing complexity, there is a definite tendency for the differences between the performances of each age group to increase as the difficulty of the task is increased. (*See* Figure 2.)

Individual Differences.

It will be appreciated that as yet we have spoken only of the result in terms of the mean values for each task, but the standard deviations show that the individual results are more complicated than has so far been made out. As would be expected when the

FIGURE 3



Individual Results at Stage III.

task became more difficult the mean values not only increased, but the variations between individuals became accentuated. The effect of this was particularly marked with subjects in the two oldest groups. In order that as comprehensive a picture

as possible might be given, Figure 3 sets out the individual distributions for Stage III. These results not only indicate the general trend as given by the means, but how many individuals in each group fail to conform to it. This variability amongst older subjects is such a general finding (*see* Thorndike, 1928; Welford, 1951) that it will not be discussed here. It has to be accepted that in learning experiments age is a fickle variable, unequally influencing performance from one individual to the next, but inexorably depressing the standard of a whole group of subjects.

Categories of Mistake.

So far the customary measurements of mistakes and time have suggested that the changes in the position of the index card have considerably increased the difficulty of the task. Now by examining the kinds of mistakes which were made it is hoped to be more precise about the effects. Accordingly, the two types of mistakes already discussed have been analysed separately and are given in Table III.

TABLE III

DISTRIBUTION OF TOTAL ERRORS AT STAGES I, II AND III

Age Group	*Total Errors*	*Errors Type I*	*Errors Type II*	*Random Errors*
		Stage I		
15–24 ..	12	6	–	6
25–34 ..	13	8	3	2
35–44 ..	26	5	5	16
45–54 ..	26	3	4	19
55–64 ..	36	2	4	30
65–72 ..	31	4	5	22
TOTALS ..	144	28	21	95
		Stage II		
15–24 ..	29	2	4	23
25–34 ..	32	7	7	18
35–44 ..	45	8	7	30
45–54 ..	85	17	22	46
55–64 ..	73	17	21	35
65–72	150	50	52	48
TOTALS ..	414	101	113	200
		Stage III		
15–24 ..	40	10	13	17
25–34 ..	85	18	29	38
35–44	136	44	50	42
45–54 ..	235	76	85	74
55–64 ..	336	116	114	106
65–72 ..	479	156	226	97
TOTALS ..	1,311	420	517	374

Errors Type I.

It will be observed from Table III that at Stage I there were not many errors of this first type; 64 subjects only contributed 28 mistakes. But at Stage II there were

101 errors, whilst at Stage III this had risen to 420, a fifteen-fold increase over Stage I. It will be appreciated that the only reason why subjects changed the order of their mental procedures and made this mistake was that the position of the index card was moved. Their "reasoning" as expressed by one subject was, "the lights and the number on the card are close together; when a light comes on it seems to mean the number immediately below it."

Subjects in aligning a light with the card numeral in front of it, were, of course, making an association which was opposed both to the instructions for the task and to how they had hitherto carried them out. This seems to indicate certain priorities in their treatment of data, for having followed out the above procedure they realised that they had not fulfilled their instructions in that a different substitution was uncompleted. So they then, instead of aligning numeral with key, found the key whose spatial position number was corresponding with the numeral on the card, that is they reverted to a version of the substitution procedure which they should have done earlier.

Errors Type II.

It was not anticipated that this type of error would be as prevalent as it in fact proved to be. Table III shows that it occurs even more often than that of Type I. This is surprising since the mistake seems almost too naïvely wrong to have happened so often. However much subjects might be influenced by a tendency to align the lights and the card numerals, it had been argued that subjects would surely be aware that they had omitted some necessary steps in achieving this patent error. However, from watching subjects perform, it was noticeable that these errors occurred more spontaneously than those of the first type—it was often a subject's quick reaction to the problem. As a result the procedure often seemed to be tried, but it did not appear to produce the same degree of bewilderment when it proved to be wrong. Subjects were prepared to accept it as a mistake with remarks such as "Of course that is wrong!" but this did not prevent them offering it as a solution at the next serial position when they were in difficulties. Hence the huge number of mistakes of this type.

Random Errors.

From Table III, it will be seen that whereas at Stage I two-thirds of the errors fall into this category, the figure is less than one-third at Stage III. It is not, of course, being claimed that the analysis of the two major types of mistake covers all the wrong mental decisions which subjects took at the last stage, but it is felt that the random errors are sufficiently small to be accounted for by inevitable minor aberrations, and those occasions when a subject did become so confused that he hit all the keys in succession to try to find the correct one. To substantiate this point it should, perhaps, be mentioned that for any one response the probability of hitting by chance the right key, or a particular one of the two types of errors was 1 in 12, whilst that of making random errors was 9 out of 12. Thus, whenever a subject indulged in making a random selection he was likely to make considerably more random errors than any other kind.

Repetition of Mistakes.

The number of errors at Stage III, given in Table III, would suggest that the same mistake was frequently made by the same subject. This was particularly true of the oldest subjects who must have been repeating over and over again the same two types of errors. To achieve as they did at Stage III 156 "Type I" errors and 226 "Type II" implies that on the average each subject in finding the required 20 correct responses, made nearly 40 incorrect responses of the same two types.

But even so a subject might have repeated most of these two types of errors at the same rather than at different serial positions. The mean number of first errors at this stage, as given in Table II, makes this unlikely for the older groups, but the point can perhaps be settled most clearly by considering an individual record such as that in Table IV. This result is in many ways typical of the subjects in the over 65 age group. It records the first 10 serial positions at Stage III, where a subject made 25 errors, of which 10 were Type I, 14 Type II, and one was random. From the table and its accompanying explanation of the responses, the predominant feature of such a performance was that a subject, after making certain types of errors at one serial position and subsequently amending them by following the right procedure, was unable to continue correctly. Out of the 10 serial positions, at 7 both types of mistake were made, and it will be observed that the three correct positions did not occur consecutively, but were interspaced between the mistakes. It was this ephemeral quality of the solution which was so evident; far from being permanent it was typical of this performance, as of so many, to make a mistake, to be able to correct and then to make just the same type of mistake at the next serial position.

TABLE IV

A Typical Individual Record (Subject aged 68) for Stage III: First 10 Responses

Position of lights in serial order	1	9	3	12	10	6	8	5	7	4
Correct keys in serial order	10	1	7	9	6	11	5	2	12	4
Subject's Responses ..	1* 9† 1* 1* X	I	11† 11† 3* 3* VII	7† 12* 12* IX	10* 1† VI	XI	2† 8* V	5* 8† 8† 5* 8† 5* II	7* 3† 5r 7* XII	IV
Total Errors ..	4	0	4	3	2	0	2	6	4	0

† = Type I errors. (Card numeral equals spatial position number of key.)
* = Type II errors. (Alignment procedures only.)
r = Random errors.
Roman Numerals = Correct keys.

The table should be read in conjunction with Figure I, Stage III.

The subject is presented with Light I. He aligns it with the card numeral and then aligns the numeral with the key position and strikes key 1 (Type II error). He then reads the number on the card immediately underneath the light and strikes the key whose spatial position corresponds to this number (Key 9) (Type I error). He then reverts to his first procedure of taking the light position as being equivalent to the key position and twice hits Key 1. Finally, he goes through the correct procedure of finding the position number of the light, finding that digit on the card and then hitting the key in line with that numeral (Key 10). This changes the light from 1 to 9. Subject here presses the right key, and the light changes to position 3, and so on.

Note how often the subject makes the same two types of mistakes at a serial position, then gets it right, only to repeat the same mistakes at the next serial position.

Summary of Older Subjects' Performances.

Bearing in mind the analysis of the errors of an individual subject which has just been made and the error figures presented in Table III, the total performance of the

over 65 group can be summarised as follows. Each of these 10 subjects had to make a correct response at 20 positions of the lights, making a total of 200. Of these 200 responses 128 were wrong. (First Errors, Table II.) Thus, as this mean for the errors is fairly representative, it can be said that a subject in this group in making 20 correct moves made mistakes at nearly 13 different positions, and repeated at least one of the same two types of mistakes at each of these 13.

The results of the oldest age group have been given in some detail because they do represent an extreme form of a tendency which is evident enough amongst all the older groups. Faced with the problem of how to carry out their instructions, subjects were putting forward consistently two types of responses which were proving wrong; and, as with the oldest age group the outstanding characteristics was that in spite of always having to find, and in fact finding, the correct response before moving to another serial position, they were subsequently repeating these same two types of mistake. Had subjects been able to accept the evidence, both positive and negative with which they were confronted, then they should have been able to manipulate the variables involved in the procedure, probably not with complete success at the beginning, but showing a gradual improvement. It was this which the older subjects in particular could not do at the harder task; the shape of the error curve at Stage III (Figure 2) suggests that it was a difficulty which increased rapidly with age.

IV

Discussion

As this discussion does not aim to be exhaustive it will make no further reference to the behaviour of older subjects nor to the reasons why items which are spatially contiguous should be associated. But it will comment on two features, the Prediction of Mistakes and the Repetition of Errors, and precede this by a brief description of some pilot work to the experiment which has some bearing on these issues.

A Pilot Study.

In making preliminary observations the procedure was somewhat different. The subject began the task, as now, with the index card immediately beside the keys, but he was instructed that as he continued to do the task the card would gradually move away from the keys towards the lights. He was to ignore this change as far as possible and to carry on with his procedure no matter what the position of the card. This gave rise to some amusing and illuminating happenings. A subject would begin the task correctly, but as the card moved from the keys his responses would gradually take longer until, when the card was near the lights, he would perhaps stop altogether in some confusion. The experimenter would not say anything, but slowly bring the card back towards the keys, and as the card approached them, the subject would be able to resume successfully. It was a striking point that with some subjects this whole procedure could be repeated several times with just the same result and without the subject being able to analyse why he was able to do the task at some points and not at others.

It will be appreciated that this was a fascinating phenomenon to watch in so far as the difficulty of the operation could actually be measured on a linear scale. The "blocking" of the mental processes could be imposed or removed at will by sliding the card a matter of a few inches. It had been intended to present the experiment using this psycho-physical method, since it does establish this feature, but there was the objection that some subjects became so mystified by their failure that they suspected some form of "trickery" in the moving card.

Prediction of Mistakes.

The behaviour in the Pilot Study is, of course, an illuminating reiteration of that at Stage III, where the index card was immediately in front of the lights. At Stage III the difficulty was not so much one of an inability to apply an instruction because it was "forgotten," as an inability caused by one piece of information taking priority over another; that is in this case, the apparently contrary information from the spatial proximity of the lights and the index card overriding the original instructions. There are good grounds for saying that the failure was not one of "forgetting" the instructions, for the Type I errors, as already noted, are mainly caused by reversing the sequence of events—an indication that one stream of information was temporarily overriding or "blocking" another.

If subjects had been completely unable to do the task then it would have seemed, as it does in the problem-solving experiments of the "detour" type, that they were unable to think out the correct solution because they were too dominated by their interpretation of the perceptual situation confronting them. In the "detour" kind of experiments the assumption is generally made that the correct solution does not occur to a subject because there is one stream of evidence from the visual scene "suggesting" that the solution lies in one direction and apparently blinding a subject to an alternative. To solve the problem this misleading indication has to be overcome, and when this is achieved the experimenter has the difficulty of explaining what it is from a subject's previous experience, his mode of thinking, etc. which has aided him to achieve his solution.

In the present experiment whilst the evidence from the visual field—the external source—is comparable to that in the problem solving experiment, the information from the internal source has one important addition, namely, the immediately preceding experience of assimilating and executing the instructions for the task at the earlier Stage. Thus a subject is not searching, as he is in the Problem-Solving experiments, within his whole range of experience for a solution—he knows that this one lies within his immediate past. This is not attempting to deny the importance of a subject's general approach and mode of thinking, but emphasising the relevance for this task of one particular experience in it.

This kind of process whereby incoming data have to be reconciled with contrary instructions has often been described in terms of perceptual reorganisation. Here, on the basis of what we have discussed, it would seem that the procedure could be stated as follows: the organism was receiving data from the visual display. This input was subject to two particular kinds of modification and especially at Stage III the task was to reconcile these contrary indications.

(i) Items in a display which are spatially contiguous tend to be mentally associated. To do this would give rise to the two types of predicted errors and in the light of this occurence it can be claimed that there is phenomenal evidence how the input data were being treated.

(ii) Instructions had previously been assimilated that the perceptual data were not to be so treated, and a particular procedure was to be followed. The correct responses at Stage III indicate when this was achieved.

At the same time it should be noted that all subjects, without exception found, difficulty in carrying out Stage III; that is, they all took much longer than in the earlier stages and they nearly all made some errors. It would seem that the input had first come under the influence of the habitual mode of interpreting spatial contiguity (that is (i)); in other words the organism was first distorting its information before it tried to follow out the procedural instructions (ii). The experiment does not allow us

to be dogmatic on this point—it could be argued that the two procedures might be interacting simultaneously. But both the manner of subject's performances and the results would suggest that the temporal priority for these procedures was for data on their reception to be immediately interpreted by the organism according to its habitual modes of operation, and any analysis which was particular to conditions of the moment was subsequent to, and as here, often in opposition to the interpretation which had already been conducted. The whole problem may, in fact, be no more than this—a relatively simple analysis which has to break down the already established linkage of items. In this respect the experiment is a fair study of thinking, and it is of note that many subjects, after making some responses at Stage III correctly did, in fact, go on to make errors and become confused—it appeared that the established habitual procedure was able to assert itself when for any reason a hiatus occurred in a subject's thinking.

It is claimed then that the experiment in studying the adjustment between two contrary procedures and in being able to predict their respective results can be a little more precise about what are the exact difficulties which confront an organism in such a situation and how it has and has not adjusted to them.

Repetition of Mistakes.

The section in the results on repetition has brought out how frequently errors are repeated; at the risk of exhibiting the feature under discussion the following points seem worthy of emphasis.

We have argued that the mistakes are not a result of "forgetting" but of certain streams of information taking precedence over others—to a system of priorities. This is often a main difficulty of the problem-solving experiment, that the already held idea cannot be eradicated however often it has proved to be wrong and however much the subject himself is aware of its inadequacy. The effect then seems to be similar whether the mistaken idea arises from previous experience or from some feature in the immediate environment or some combination of both. The importance to accurate thinking of this ability to drop errors quickly has been generally recognised, in the field of mathematics notably by Hadamard (1945). From a slightly different standpoint Bartlett (1950) has considered how far subjects are prepared to continue in a course of actions against increasingly contrary indications. The present experiment partly fulfils some of his stipulations and throws some light on the question. The task has been so devised that the likely number of variants are few. If subjects continually do the task incorrectly they continue to repeat the same mistake though the evidence that this type of response is wrong is increasing; but equally they cannot move from one serial position to the next without following the right procedure and thereby receiving positive evidence on the point. The obvious reluctance, if not the disability of subjects to act upon this evidence, whether of the positive or negative variety is definite enough.

But the important issue for the writer is that this outstanding feature of problem-solving behaviour seems to be typical of what he observed in a rote learning situation with human subjects. In their rote learning there was the same reluctance by the poorer performers to accept information at a stage when it should have been patently obvious that the solution to which they were adhering—their already learned version—was wrong. Quick learners on the contrary had this ability to amend easily, to accept information at its face value and not to "argue" against it. It was this reluctance to discard their own ideas which characterised a poor performance both in the learning and in the present experiment. Not only were they puzzled by their mistakes, but n many instances there was a tendency, often overtly expressed, to argue that the

mistake was right, that the apparatus was faulty or something of that order. The frustrated reactions which were evoked were strikingly similar in both experiments. They were only to be solved by a definite act of "deliberation," in Johnson's use of the term (1944), a deliberation which contrary to his statement, was as much a characteristic of a rote-learning experiment as of the present problem. This seems reasonable enough—it is the same "biological" mechanism which is operating in either case and it is a feature of its functioning that new information has to be assimilated in relation to that which the system is already holding. Where instructions conform with habitual procedures they are quickly learned but, as here, the objectively same instructions may be only slowly acquired if they appear to contradict established habits.

Conclusion.

For the subjects who attempted this experiment it represented both a learning and a problem-solving task. They learned to carry out an operation, but they were also presented with a situation in which they had to think. As they had been given the solution they did not have to think out what that was, but rather had to consider how they were to apply it. Obviously this is not typical of all problem-solving experiments; here we have followed a restricted method by metaphorically turning the problem around and presenting a subject with the usual end product, the solution. This is very different from the more "intriguing" problems where the individual may have ranged over much of his imaginative and intellectual experience in searching for the solution. But it may well be that the more open type of problem is at present too ambitious for our experimental controls—we get some sort of result, but are too much in the dark how it has been obtained. The present technique does give us some precision which is open to further analysis. By predicting certain types of mistake it is possible to confirm what it is that is holding up a subject's progress. The error "solutions" which were put forward were those which had been considered and labelled. For a subject, progress was not barred by blankness but by wrong "solutions". For the experimenter, there was not a long and uninformative hiatus but ample opportunity to observe the interplay between the instructions and the changing spatial contiguities.

It is also felt that this use of the spatial dimension, more in the manner of the researcher on equipment design than in the traditional detour experiments is a useful precedent for problem studies. It need not be a barren model. The temporal dimension lends itself equally well to a similar experimental method, whilst other qualities such as size, shape or colour, could be treated on similar lines.

This study was carried out whilst the writer was a member of the Nuffield Research Unit into Problems of Ageing, Psychological Laboratory, Cambridge. It is desired to make acknowledgement to Messrs. Rowntree & Co. for their kindness in providing the facilities and the subjects for the experiment.

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SELECTIVE EFFECTS OF AN ANAESTHETIC DRUG ON COGNITIVE BEHAVIOUR

BY

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The prediction has been tested that under the influence of an anaesthetic drug, nitrous oxide, cognitive performances undergo differential impairment, the extent of which is positively correlated with the "complexity" of the task.

Ten kinds of performance were investigated, ranging from speed of finger tapping to reasoning by analogy. The relative complexity of each task was determined, in accordance with conventional criteria, from its respective qualitative category or "level"—relational, associative, and motor—and within each category from qualitative analysis of the component processes involved in its execution. A simple group difference design was used, involving two groups of 50 subjects each, matched for age and sex.

Significant deterioration as a consequence of drug administration occurred in the performance of all tasks. On the whole, the more complex a task the more did it tend to be impaired. Motor performances were, however, impaired to a greater extent than had been predicted. The possible significance of these findings is discussed.

Introduction

Behaviour can be modified by various drugs which act on the central nervous system, among them those which in higher doses produce anaesthesia. The precise mechanisms through which anaesthetic drugs act are imperfectly understood (Butler, 1950). Except for barbiturates, the effects of most of the well-known anaesthetics, including alcohol, ether, and nitrous oxide, are usually described following Hughlings Jackson's conception (1884) in terms of a law of "descending inhibition" (Harris, 1951; Himwich, 1951; Wilson & Schild, 1952). According to this the phylogenetically newer structures of the nervous system—the "higher centres"—mediating the most complex forms of behaviour, are depressed earlier and to a greater extent than the older "lower" structures.

Some psychologists have seen in this selective action corroboration for schemes of classifying "mental processes" according to their differential "complexity." Thus McDougall (1908, 1948) cited the allegedly progressive disorganisation of behaviour induced by alcohol as evidence for three mental "levels"—"intellectual," "sensory-motor" and "reflex." Recently Moursi (1952) has argued similarly in support of the "hierarchical" scheme developed from results of factor analyses by Burt (1949, 1949*a*), following which every cognitive process can "according to its relative complexity"—defined essentially in terms of correlation with intellectual ability—be assigned to one or other of four principal "levels" appropriate to "relational," "associational," "perceptuo-motor" and "sensory-motor" behaviour respectively. Diverse classifications of behaviour are, of course, permissible, and those like Burt's are useful mainly because they correspond to familiar qualitative categories. Nevertheless, agreement between classifications developed from two such different criteria as a form of psychological analysis on the one hand and the selective action of drugs on the other, would contribute to the understanding of both.

The assumptions behind the law of descending inhibition require modification in the light of contemporary views on relations between the nervous system and behaviour. The evidence is in most respects still inconclusive and, as is well known, there can be marked differences between effects of different anaesthetics. However,

it is at any rate broadly probable that there is a positive correlation between complexity of interneuronal organisation in the nervous system and complexity of overt behaviour, and also between complexity of interneuronal organisation and susceptibility to the action of anaesthetics (Bárány, 1947; French *et al.*, 1953). From this it should still follow that behaviour will be impaired selectively and according to its relative complexity by a given amount of anaesthetic. Relevant findings by previous investigators, though numerous especially on alcohol, are difficult to interpret because of divergencies in design and techniques and because most of them demonstrate the presence or absence of an effect on individual kinds of performance without comparable measurement of the magnitude of disturbance. Most findings seem not incompatible with expectation (e.g. Varner, 1933; Gantt, 1935; Newman *et al.*, 1942; Lauer, 1939; Mead, 1939; Jellinek & McFarland, 1940; Spragg, 1941; Wechsler, 1941; Masserman, 1945, all on alcohol; McKinney, 1932; Marshall, 1937, on nitrous oxide; Case & Haldane, 1941, on "nitrogen narcosis" attendant upon increased air pressure). Some conflict (e.g. Seward & Seward, 1936; Davis *et al.*, 1941, both on alcohol). In particular, the relative susceptibility to anaesthetics of relational and associative behaviour on the one hand and of motor behaviour on the other has not been adequately explored.

The main purpose of the present investigation was to examine the effects, which have been little studied hitherto, of the anaesthetic gas nitrous oxide, in a concentration not involving loss of consciousness, on several aspects of cognitive behaviour. It was predicted that (i) under the influence of nitrous oxide cognitive behaviour tends to deteriorate, and (ii) this deterioration occurs selectively; the more "complex" a performance the more it is impaired. A brief preliminary account of some of this work has already been published (Steinberg, 1951); fuller details are contained in a thesis by the author (Steinberg, 1953).

Method and Procedure

1. Experimental Design.

The method of difference design used is illustrated in Table I. One hundred subjects, all university students, were divided into two equal groups matched for age and sex. Each subject attended on two occasions, separated by one week. On the first occasion treatment was identical for members of both groups, measures of performance in 10 different cognitive tasks or "tests" being obtained from each subject. On the second occasion measures

TABLE I

Experimental Design

Group	*Treatment**	
	Trial I	*Trial II*
Experimental 50 subjects	10 cognitive tasks No Drug	10 cognitive tasks Drug
Control 50 subjects	10 cognitive tasks No Drug	10 cognitive tasks No Drug

* Trials I and II were separated by one week.

of performance in 10 tasks similar to those given earlier were again obtained from all subjects; but experimental subjects inhaled the drug throughout this phase, while control subjects inhaled air. Thus the presence or absence of the drug is the independent variable, and behaviour in the test series constitutes the dependent variable. If it can be shown that the two groups are equated on initial performance, comparison of their

subsequent performance enables the drug effect to be measured. Finally, the experimental design makes possible comparisons between the different kinds of cognitive behaviour sampled in respect of any differential changes undergone by them under the influence of the drug.

II. Administration of the gases.

Nitrous oxide (N_2O) is an anaesthetic gas which, administered by inhalation, is rapidly absorbed and excreted through the lungs. The apparatus used enabled administration to be maintained at a relatively constant rate for any desired period of time. The flow of gases was measured by rotameter-type flow-meters and delivered by an open circuit to a reservoir bag of $3\frac{1}{2}$ gallons capacity connected by corrugated rubber tubing to a modified R.A.F. oxygen mask. A microphone in the mask enabled the subject to communicate with the experimenter. The apparatus delivered 30 per cent. nitrous oxide in oxygen at a rate of 15 litres per minute to all experimental subjects, this concentration being chosen as preliminary experiments had shown it to induce marked changes in most subjects' cognitive behaviour without seriously impairing their co-operativeness. The air inhaled by the control subjects was administered from the same apparatus and at the same rate. Any unused surplus escaped through expiratory valves in the mask. Since nitrous oxide normally has a distinctive smell, all gases were perfumed by inserting into the circuit a filter-paper impregnated with lavender oil. Five minutes' preliminary inhalation was always given prior to the testing session proper, since this period has been shown to be adequate for establishing a relatively stable equilibrium between the concentrations of nitrous oxide in the arterial and venous blood supply of the brain (Kety & Schmidt, 1948).

III. Tests of behaviour.

The tests chosen cover a wide range of cognitive behaviour, taking into consideration the practical requirements of brevity, standardisation, repeatability, and convenient administration to subjects hampered by wearing somewhat cumbersome apparatus. The following 10 tests were used:—

A. Relational.

1. "Non-Verbal Analogies": a multiple choice test containing 30 diagrammatic items arranged in order of increasing difficulty. Score: number of items correctly answered in $2\frac{1}{2}$ minutes. This test and test 2 were adapted from standardised material kindly supplied by Dr. Edgar Anstey.

2. "Verbal Analogies": a similar test, but consisting entirely of verbal material.

B. Associative.

3. "Arithmetic": the subject added as quickly as possible sums of four 2-digit numbers. Score: number of individual columns correctly added in 2 minutes.

4. "Digit-span Backwards": the subject repeated in reverse order sequences of digits of increasing length presented to him orally at the rate of one digit per second. Score: number of digits in longest sequence repeated in correct order, two trials being allowed for each length of sequence.

5. "Fluency 'Flowers' ": the subject said as many names of flowers as possible in the time allowed. Score: number of names of flowers given in 60 seconds. (Eysenck, 1947.)

6. "Fluency 'Things to Eat' ": as 5 above, but calling for names of things to eat. (Eysenck, 1947.)

7. "Digit-span Forwards": as 4 above, except that the digits were to be repeated in the same order as presented.

C. Motor.

8. "Dotting": McDougall-Schuster Disc Dotting Machine embodying a revolving spiral of irregularly placed dots at which the subject aimed with a pencil. Score: number of dots "hit" before two consecutive misses.

9. "Ball-bearing": the subject inserted with a pair of forceps steel balls as quickly as possible into a vertical tube. Score: number of balls inserted in 40 seconds. (The apparatus resembled the R-V manual dexterity test developed by the National Institute of Industrial Psychology.)

10. "Tapping": the subject tapped with his hand as quickly as possible a Morse key connected to an electric counter. Score: number of taps in 30 seconds.

Parallel versions were used for tests 1, 2, 3, 4 and 7 in the two presentations.

The tests have been listed above in the order of their relative "complexity". For the purposes of the present experiment this was determined for each test first from its respective qualitative category or "level," i.e. relational, associative, and motor. This classification corresponds to Burt's, except that his two "lowest" categories have been combined into one. Individual tests in each category were then ranked by qualitative analysis of the component processes involved in their execution. Thus, for example, "Non-Verbal Analogies" ranked higher than "Verbal Analogies" on account of its less familiar content—diagrams as against words—and both these tests, being "relational," ranked higher than all the remaining tests. The complete rank order was determined unanimously by three judges working independently. Some further suggestive corroboration was obtainable for the order assigned. First, Moursi (1952) ranked four of his tests "Non-Verbal Analogies," "Verbal Analogies," "Verbal Fluency," and "Digit-Span Forwards"—which closely resemble those used in the present investigation, in the same order. His ranking was based on the relative saturation in the general factor. Secondly, where tests in the present experiment were scored along comparable scales, the relative size of the mean scores in the first trial is a possible index of differential complexity, and, as can be seen later from Table II, is compatible with the ranks already assigned. For example, "Digit-Span Backwards" gave rise to a lower mean score than "Digit-Span Forwards," and "Fluency 'Flowers'" to a lower score than "Fluency 'Things to Eat'".

Results

Table II summarizes the results, in raw scores, obtained by the two groups of subjects in the ten performances tested during both phases of the experiment.

In order to test the two predictions under investigation, these results were analysed as follows:—

(i) Matching of experimental and control groups in respect of initial test performance.
(ii) Overall effect of the drug on test performance.
(iii) Differential effects of the drug on test performances.
(iv) Comparison of observed and expected differential drug effects.

In addition, so as to obtain measures of reliability of the tests used, correlations were calculated between the test scores obtained in the first and second trials by the control group. The resulting coefficients ranged from + 0·573 to + 0·888 and were all statistically significant at the 0·001 level.

(i) *Matching of experimental and control groups in respect of initial test performance:*

To test the comparability of the two groups in respect of initial performance, Hotelling's T test using "paired scores" was used (Hotelling, 1931), the null hypothesis being that, assuming equal variances and co-variances, there was no difference between the two groups in respect of mean scores on all ten tests. T^2 was found to be 13·11, and the corresponding F ratio 0·95, which is not statistically significant ($P > 0·2$). Hence the null hypothesis was accepted and the two groups were regarded as satisfactorily equated on initial performance.

(ii) *Overall effect of the drug on test performance:*

To take into account all the information available, both in respect of the matching of individuals between the two groups and of the testing and retesting of each individual in each group, the calculation of the drug effect was based on "second-order differences." For each subject ten difference scores were calculated by subtracting his first score from his second score on each test. Then for each matched pair of subjects ten second-order difference scores were calculated by subtracting the difference scores of the control subject from those of the experimental subject. Hotelling's T test was used to test the overall statistical significance of these second-order differences, the null hypothesis tested being that the drug had introduced no

TABLE II

SUMMARY OF TEST RESULTS IN RAW SCORES

Test	Parameter	Experimental $N = 50$			Control $N = 50$			2nd order diff.
		Trial I	Trial II	Diff.	Trial I	Trial II	Diff.	
1. Non-Verbal Analogies	Mean	10·50	8·22	− 2·28	9·64	11·06	+ 1·42	− 3·70
	s.d.	2·40	2·77		2·55	2·21		
2. Verbal Analogies	Mean	15·10	13·36	− 1·74	14·24	18·80	+ 4·56	− 6·30
	s.d.	4·51	4·13		3·77	3·78		
3. Arithmetic	Mean	23·46	14·94	− 8·52	24·84	24·42	− 0·42	− 8·10
	s.d.	7·40	7·23		7·00	7·71		
4. Digit-Span Backwards	Mean	5·66	4·62	− 1·04	6·06	6·52	+ 0·46	− 1·50
	s.d.	1·53	1·35		1·39	1·43		
5. Fluency "Flowers"	Mean	18·04	15·42	− 2·62	17·20	19·72	+ 2·52	− 5·14
	s.d.	5·52	5·72		4·98	5·50		
6. Fluency "Things to Eat"	Mean	28·50	23·30	− 5·20	28·18	28·44	+ 0·26	− 5·46
	s.d.	7·11	7·48		7·68	8·28		
7. Digit-Span Forwards	Mean	7·58	7·02	− 0·56	7·78	8·00	+ 0·22	− 0·78
	s.d.	1·56	1·45		1·24	1·13		
8. Dotting	Mean	151·24	109·10	−42·14	168·06	178·18	+10·12	−52·26
	s.d.	44·82	36·89		46·83	52·06		
9. Ball-Bearing	Mean	16·00	13·12	− 2·88	16·52	17·02	+ 0·50	− 3·38
	s.d.	1·91	2·04		2·29	2·51		
10. Tapping	Mean	198·48	172·32	− 26·16	201·34	199·36	− 1·98	− 24·18
	s.d.	25·28	20·53		22·84	22·06		

difference in the performance of the experimental group, as compared with the control group. The T^2 ratio was 35·94, and the corresponding F ratio 25·47 which, with d.f. 10 and 40 is highly significant statistically ($P < 0{\cdot}001$). Hence the drug had been shown to have had a significant adverse effect on test performance.

In addition, individual t ratios, using the formula for "paired scores," were calculated and showed that the mean second-order differences in respect of each of the ten tests were statistically significant at the 0·005 one-tail level, or higher. It is of interest also to note from inspection of the standard deviations given in Table II that variability of performance appears to have been fairly uniform throughout, including that of the experimental group when the drug was being given.

TABLE III

DIFFERENTIAL IMPAIRMENT OF PERFORMANCES ATTRIBUTABLE TO DRUG

Tests (in rank order of expected impairment)	*Observed impairment*	
	s.d. difference score	*Rank order*
1. Non-Verbal Analogies ..	1·471	3
2. Verbal Analogies	1·508	2
3. Arithmetic	1·120	5
4. Digit-Span Backwards ..	1·016	6
5. Fluency "Flowers"	0·975	8
6. Fluency "Things to Eat" ..	0·738	9
7. Digit-Span Forwards ..	0·552	10
8. Dotting	1·121	4
9. Ball-Bearing	1·591	1
10. Tapping	1·002	7

It will have been realized that for the purpose of these experiments "deterioration of performance" is being defined "operationally" simply as a reduction in test scores, and that the test scores are in all cases based on quantity of correct output in a given time and/or a given number of attempts. Hence a drop in score is equivalent to a decrease in efficiency. For the three written tests—"Non-Verbal Analogies," "Verbal Analogies," "Arithmetic"—it was, however, also possible to examine whether the drop in score was attributable primarily to a decrease in the total number of test items attempted, to an increase in the number of errors, or to both. The statistical significance of the differences between the experimental and control groups in respect of all relevant pairs of distributions of these two variables was calculated by means of χ^2 tests using medians (Mood, 1950). This method of calculation was adopted because of the pronounced skewness of some of the distributions. The results showed that neither for the total number of items attempted nor for the number of errors were the differences between the experimental and control groups statistically significant in the

first trial, but they were significant, at the 0·01 level or higher, in the second trial in respect of all three cognitive performances considered. This suggests that both factors contributed to the reduction in test scores during inhalation of the drug.

(iii) *Differential effects of the drug on test performances:*

To test the second prediction, that deterioration of performance occurs selectively and in accordance with the relative complexity of the performances, the test scores from different tests had first to be made comparable. The second-order difference scores were accordingly converted into standard deviation difference scores, i.e. the ratio was computed of the mean second-order difference to the standard deviation of test scores obtained by both groups in the first trial. These standard deviation scores could be used as measures of the effects of the drug, and the different tests arranged in rank order accordingly, from most to least impaired. The results are shown in Table III and illustrated in Figure 1. It will be seen that the relational tests were impaired to a greater extent than associative tests, but that performance in motor tests was also much affected, the Ball-Bearing test appearing the most sensitive of all.

FIGURE 1

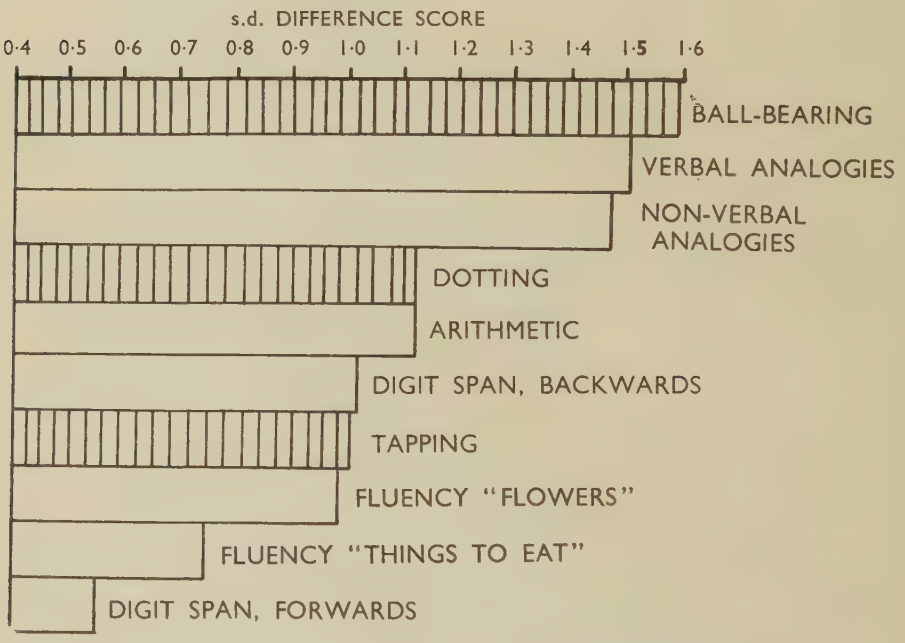


Diagram of differential impairment of performances attributable to drug.

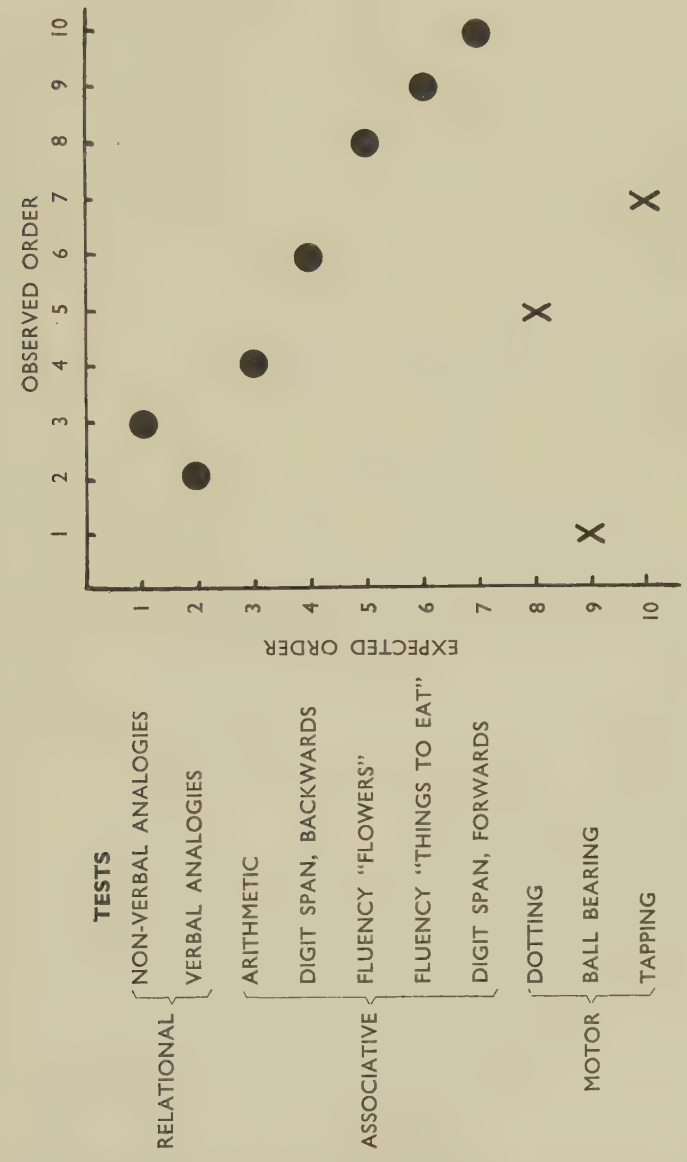
It may be noted that the method of conversion into standard scores described does not enable the statistical significance of the differential impairment between the different tests to be estimated, nor does it take account of correlations between the tests in respect of second-order differences. As the calculated values of these correlations were found to be almost uniformly small it seemed reasonable to omit such a refinement.

(iv) *Comparison of observed and expected differential drug effects:*

The final step in testing the second prediction was to compare the differential drug effects actually found with those expected on the basis of the differential

"complexity" of the performances tested. As has been explained, the tests used had been ranked from test 1, the most complex, to test 10, the least complex. Hence differential impairment of performances under the influence of the drug was expected to follow the same order, test 1 being expected to be most impaired and test 10 least.

FIGURE 2



Relation between expected and observed orders of impairment

The observed rank order of impairment compared with the expected order gives a Spearman rank correlation of + 0·285. This fails to reach statistical significance ($P > 0{\cdot}05$). It will be noted from the dot diagram in Figure 2, however, that the discrepancies between the expected and observed rank order are due almost entirely

to the motor tests. If these are eliminated from the rank orders, the correlation rises considerably, to + 0·964 (P = 0·0014). These results suggest that the prediction has been substantially verified as far as the relational and associative tests are concerned; the motor tests, however, appear to have been impaired to a different and greater extent than was predicted in terms of the criteria of relative complexity here adopted.

Discussion and Conclusions

The results described have the following implications:

(*a*) The overall efficiency of cognitive performance deteriorates significantly under the influence of a sub-anaesthetic concentration of nitrous oxide. It has, in addition, been shown that there was significant impairment of performance on each of the individual cognitive tasks investigated, and that in the three written tasks this impairment took the form both of decreased total number of items attempted and of increases in the number of errors. Of particular incidental interest is the definite decline which occurred in verbal fluency, in view of the fact that nitrous oxide and similar drugs are often used in psychotherapy with the object of making the patient more loquacious (Horsley, 1943). It should be pointed out that it is not possible on the basis of the present investigation to decide how far deterioration of performances was due to a lowering of cognitive ability as such, and how far to such factors as reduced motivation, impaired concentration, or interference from various physical and psychological symptoms experienced during drug administration. However, there is no correlation between individual differences in the frequency with which these latter were reported and individual differences in measures of impairment of cognitive performance. This suggests that the symptoms did not have any systematic effect on cognitive performance. In three of the tests, as has been described, significant increases occurred in the number of items attempted but answered wrongly. Thus there is a possibility that although subjects under the influence of the drug were less able to make correct solutions, they may have become more willing to guess—an interpretation supported by comments made by several subjects.

(*b*) In the case of relational and associative performances, the relative amount of deterioration is closely related to the "complexity" of the task, as determined from an analysis of qualitative characteristics. The more complex a performance, the more it tends to deteriorate. The correlation between the expected and obtained rank orders of impairment, excluding the motor tests, was very high.

(*c*) Motor performances are, however, capable of being impaired to a greater extent than was predicted in terms of the definition of complexity adopted. Performance in all three motor tests used was more impaired than performance in some of the associative tests; and the Ball-Bearing test was affected to a greater extent than all other tasks. Detailed generalizations cannot justifiably be based on results from only three tests. Nevertheless, inspection of the data does perhaps suggest that relatively complex motor tasks, such as performance in the Ball-Bearing or Dotting tests, may tend to be more susceptible to the effects of an anaesthetic drug than very simple associative tasks, such as repeating digits forwards. Difficult associative tasks, on the other hand, may tend to be more sensitive than very simple motor ones.

The present investigation therefore suggests the tentative conclusion—which is not incompatible with some of the findings by other workers—that where the effects of anaesthetic drugs are concerned, relational and associative tasks on the one hand, and motor tasks on the other, should be considered separately. Within either category, the more complex the task, the more it is likely to be impaired. The evidence from the present experiments is not, however, consistent with the assumption that all relational and associative tasks are more complex than motor tasks, the view implicit

in the classificatory schemes of McDougall, Burt, and Moursi. From a neurophysiological point of view, a possible interpretation is that the assumption that anaesthetic drugs affect behaviour strictly in accordance with the relative complexity of the corresponding interneuronal pathways may not be true in the present case, but that those pathways primarily concerned with motor behaviour are especially sensitive to the drug used. An alternative possibility would appear to be that the complexity of neuronal organization involved in symbolic behaviour is not invariably greater than in all forms of motor activity.

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DRIVE-LEVEL AND FLEXIBILITY IN PAIRED-ASSOCIATE NONSENSE-SYLLABLE LEARNING

BY

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"High-anxiety" and "low-anxiety" subjects, selected for extreme scores on the Taylor Anxiety Scale, learned a list of paired-associate nonsense syllables in the belief that they were undergoing an intelligence test. Both groups were then given a second list of paired associates to learn, the stimulus-items being the same as those of the first list but the responses being changed. Before the presentation of the second list, half the subjects in each group were given anxiety-increasing instructions and the remaining half were given reassuring instructions.

The results verified two predictions made from Hull's behaviour theory, using the concept of fear or anxiety as a secondary drive:—"high anxiety" subjects took more trials to master the second learning task than "low-anxiety" subjects; and there was a significant interaction between initial anxiety-level and type of instructions, such that "high-anxiety" subjects who received drive-increasing instructions had a worse performance in the second part than all other sub-groups. There was no indication that "low-anxiety" subjects were significantly affected by the type of instructions received. The "high-anxiety" group had greater difficulty than the "low-anxiety" group in learning the first list, but the difference was non-significant.

I

Introduction

An increasingly popular field for experiment in recent years has been response fixation. Fixation may be defined as difficulty in abandoning a response when it is no longer adaptive, and the questions it raises are not only of intrinsic theoretical interest but also highly relevant to the problem of human neurosis, which usually involves a strange inability to give up forms of behaviour that are clearly punishing.

Some writers (e.g. Maier, 1949) have asserted that fixation resulting from frustration is a unique phenomenon which requires a special principle to account for it. But others (e.g. Farber, 1948; Mowrer, 1950; Wilcoxon, 1952) have offered arguments and experimental data pointing in a different direction. According to this other view, fixation can be explained by familiar principles of S–R behaviour theory, including the assumption that fixated responses are motivated by the secondary drive of fear and reinforced by fear-reduction.

Another relevant series of studies has been concerned with the effects of anxiety-level on performance as distinct from the effects of anxiety-reduction on learning. Spence and his collaborators have selected subjects according to their scores on the Taylor Anxiety Scale (Taylor, 1951, 1953). What exactly the Taylor Scale measures has been a matter for some controversy, but Spence's team have succeeded in verifying predictions from Hull's behaviour theory (Hull, 1943, 1952) with the assumption that a high score on the scale reflects a high drive-level (D). The predictions and experiments (Spence & Taylor, 1951; Taylor, 1951; Spence & Farber, 1953) indicate that "high-anxiety" subjects acquire a simple classical conditioned response more rapidly than others. But in complex learning (Taylor & Spence, 1952; Montague, 1953; Farber & Spence, 1953), i.e. when there are response-tendencies in competition

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with the response that is to be mastered, "high-anxiety" subjects are at a disadvantage. Since competition between responses is clearly present when one form of behaviour has to be replaced by another, the relation between anxiety-level and performance may provide a further clue to cases of fixation or lack of flexibility.

The present paper reports an experiment intended to investigate this problem with paired-associate nonsense-syllable learning in human beings. Our subjects had first to learn a response syllable to each of a set of stimulus-syllables ($S_1 \rightarrow R_1$). They had then to learn different response-syllables ($S_1 \rightarrow R_2$) to the same stimuli. The degree of difficulty in the second task is not, strictly speaking, identifiable with fixation, since it does not imply persistence of the overt responses appropriate to the first task. But insofar as the learning of the second series of responses is impeded by the effects of learning the first, we have an essentially similar situation. Our subjects were divided into four sub-groups. First of all, "high-anxiety" and "low-anxiety" individuals were selected by the Taylor Anxiety Scale as modified by Cutts (1953). Then, both "high-anxiety" and "low-anxiety" subjects were further subdivided according to the treatment received between the first and second phases of the experiment. Before attacking the second task, "experimental" sub-groups were given instructions designed to raise their anxiety-levels, and "control" sub-groups were given instructions designed to minimize their anxiety.

Our experiment tests predictions from Hull's behaviour theory as follows. (It will be noted that our reasoning parallels that used by Spence and his collaborators with reference to complex learning).

1. It is assumed that subjects with high scores on the anxiety scale have a higher drive-level (D) than those not scoring highly.

2. An increase in D will result in an increase in reaction-potential [sEr = f(sHr) x f(D)]. (This is Postulate 7 in Hull's earlier work (1943). In his last book (1952), it is further elaborated and becomes Postulate VIII.)

3. It is further assumed that probability of response evocation increases with reaction-potential. (This is Postulate 12 (Hull, 1943), and it appears to be assumed without being explicitly stated in the posthumous book (1952).)

4. An increase in D will increase the strength of all response-tendencies in the organism. If initially one such tendency is stronger than another, an increase in D will increase the advantage of that particular tendency (da -db = d (a–b) where "d" is a function of D and "a" and "b" are functions of the two response-tendencies respectively). Thus, if a subject has to substitute a new (initially weak) response for an old and stronger response, the former, before it becomes dominant, will have more "leeway" to make up.

5. (*a*) It follows that subjects with higher scores on the anxiety questionnaire will find greater difficulty in abandoning one response to a stimulus in favour of another, i.e. such subjects will require a greater number of trials to learn a new list of responses.

(*b*) Moreover, the stress-reducing instructions will decrease the disadvantage of the "high-anxiety" subjects and the stress-increasing instructions will exacerbate it. We thus predict an interaction between the variables, such that the greatest difficulty will occur with the experimental "high-anxiety" subjects.

II

The Experiment

Subjects:

The subjects were selected from the introductory class in psychology on the basis of their scores on the Taylor Anxiety Scale (Taylor 1951, 1953) as modified by Cutts (1953).

The "high-anxiety" and "low-anxiety" groups each consisted of 20 students whose scores fell respectively within the highest 32 per cent. and lowest 37 per cent. of scores for a population of 83 students. All subjects were unaware of the reason for their selection. Their mean age was 19·4 years, the mean ages for "high-anxiety" and "low-anxiety" groups being 19·5 and 19·3 respectively. The "high-anxiety" group contained 14 female subjects as compared with 10 in the "low-anxiety" group.

Apparatus:

The apparatus used for presenting the nonsense syllables was the Ranschburg memory drum, an illustration of which is shown by Katz (1948, p. 63). The time-pulse required to operate the apparatus was obtained from 3 two-volt accumulators, connected in series via a Palmer timing-unit.

Materials:

Fifteen three-letter nonsense syllables were chosen from the 0 per cent. and 7 per cent. association-value lists calibrated by Glaze and reproduced by Hilgard (1951). These were arranged into two lists of paired associates each consisting of 5 pairs—the 5 stimulus items being the same for each list. The 5 responses of the first list included 3 items of 0 per cent. association value and there were 4 items of this value in the second response list. In compiling the two lists an attempt was made, as far as possible, to conform to the rules set out by Hilgard (1951, p. 540). The stimulus items (the first members of the pairs) were marked with a red spot to help the subject to distinguish them from the responses.

Each syllable was exposed for 2 seconds, and there was a 2-second interval between each stimulus item and its associated response and between that response and the next stimulus item. Three orders were used for each of the two lists to reduce serial learning as far as possible. This follows a common practice since McGeoch and McKinney (1937) found that it is easier to learn paired associates if the order remains constant than if it is varied. The lists were each employed in 3 permutations using tables of random numbers, and these 3 permutations were used in arranging the syllables on the discs, so that for each list the different permutations always followed each other in the same sequence. A practice list containing 6 paired items of higher association value than those used in the actual experiment was presented in the apparatus once to all subjects.

Procedure:

Before the experiment proper began the subject was asked for his co-operation and requested to refrain from asking questions until the experiment was over, apart from making certain that the instructions were clearly understood. The subject was informed that he was to perform a new kind of intelligence test of greater validity than most, and he was then given information about the method of paired-associate learning. In particular, the subject had to spell out each syllable and try to anticipate the response syllables by spelling them out before they appeared in the aperture. All subjects were instructed to guess if they thought they knew a particular response item but were not sure of it. They were also told that learning would continue until they had reached the criterion of two successive errorless trials. In an attempt to ensure that the instructions had been clearly understood, subjects were given one presentation of the practice list and they could ask questions at this point if they were in doubt.

The subject then performed the first part of the experiment, having rest pauses of 30 seconds after every 15 trials (i.e. every 10 minutes). The experimenter noted both correct and incorrect responses and the number of trials required to reach the criterion. The subject then rested for 2 minutes, during which time the experimenter made a show of swiftly calculating the score obtained. Then the disc containing the new pairs was inserted in the apparatus behind the screen. Allocation to the "experimental" or the "control" treatment was by alternation, i.e. a subject was included in the experimental group if the previous one had been in the control group and *vice versa*. Subjects in the experimental sub-groups were told that their scores were below the average for university students and that they would now have a second run so that they might redeem themselves. Control-group subjects heard that they were above average for students and that they would now have a second run designed to give information on exactly how much above average they were. All sub-groups were told that the stimulus-syllables were the same as before but that the responses were new; of the two lists used, each was presented first and the other second for half the subjects in each sub-group.

III

Results

Part I. An analysis of variance was carried out on the numbers of trials to reach the criterion for the first learning task. The means were 31·25 for the "high-anxiety" subjects and 26·25 for the "low-anxiety" subjects, but no significant F emerged either for this comparison or for any other. Both Bartlett's test for homogeneity of variance and the F-test failed to show any significant differences in variance between "high-anxiety" and "low-anxiety" groups.

Part II. The means for trials to reach the criterion in the second phase are displayed in Table I. It will be seen that the experimental "high-anxiety" sub-group took longer to learn than the other three sub-groups but that the means of the other three sub-groups are closely comparable. All sub-groups, however, showed an improvement on the means for Part I.

An analysis of variance produced significant Fs for two comparisons, viz. "high-anxiety" versus "low-anxiety" subjects ($F=6{\cdot}75$, $df=1,32$, $p<{\cdot}05$) and interaction between initial anxiety-level ("high-anxiety" versus "low-anxiety") and instructions (experimental versus control) ($F=5{\cdot}31$ $df=1,32$, $p<{\cdot}05$). The difference between experimental and control groups was not shown to be significant.

Since there was a difference, though not a significant one, between the "high-anxiety" and "low-anxiety" groups in part I, it was judged worthwhile to perform an analysis of covariance on the data from both phases of the experiment. This analysis revealed once again an anxiety-level x instructions interaction that is significant at the ·05-level ($F=4{\cdot}55$) But the F for anxiety-level this time fails to reach significance. Thus, we are forced to consider the possibility that the results for the "high-anxiety" and "low-anxiety" subjects represent the summation of two effects which do not reach significance alone but do so in combination, namely a greater difficulty in learning for "high-anxiety" subjects and a greater difficulty in changing from one response to another.

TABLE I

Mean Trials to reach Criterion in Part II

	"high-anxiety"	*"low-anxiety"*	*Total*
Experimental	26·0	14·3	20·15
Control	16·4	15·7	16·05
Total	21·20	15·00	18·10

Bartlett's test for homogeneity of variance was used on the data for Part II, and the assumption of homogeneity was not confirmed ($chi^2 = 17{\cdot}5$, $p<{\cdot}05$). It was therefore held advisable to supplement the analyses of variance and covariance with a non-parametric test. Wilcoxon's T-test (Wilcoxon, 1949; Moses, 1952) was chosen and applied to the results for Part II. In view of our unidirectional predictions, a one-tailed test was appropriate. The difference between "high-anxiety" and "low-anxiety" groups turned out to be significant at the ·02-level on a two-tailed test and at the ·01-level on a one-tailed test (Rank totals (T) = 327,493). The interaction initial anxiety-level x instructions (experimental or control) fell just below the ·05-level on a two-tailed test but exceeded it on a one-tailed test (T = 363,457). Our two predictions are thus once again confirmed.

IV

Discussion

While recommendations for a wide range of real-life problems can scarcely be based with any confidence on the results of this experiment alone, we have one more study to show, like numerous previous ones, that a high-anxiety level is not conducive to a change to more adaptive behaviour from behaviour that is no longer rewarded. In the situation represented by our experiment, it is clear that initially anxious individuals find difficulty in adopting new response-patterns when they are exposed to alarming exhortations. But if they are reassured, they can be as flexible as their less anxious fellows. In everyday life, people are frequently subjected to procedures intended to discomfort or frighten them as a means of inducing a radical alteration in their behaviour. And anxious, tense persons, whose personality makes them more prone than others to fixation on undesirable or inadequate responses, are especially likely to receive this treatment in family, scholastic, industrial or military environments.

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BOOK REVIEWS

The Geometry of Mental Measurement. By Sir Godfrey H. Thomson. University of London Press. Pp. 60. 6s. 6d.

The title of this book may entice the intending reader by the suggestion that he will be shown how to take ruler and compasses to the contents of his head; alas, it is not so fascinating as that. What the author gives is a clear geometrical exposition of the processes involved in factor analysis by the centroid method, and for factor analysts who are already familiar with the concepts of mental testing and with the aims and uses of such analysis it should perhaps be prescribed reading. For the ordinary reader it lacks completeness in that it does not give any hint of the reasons for factorizing, either in general or in this particular way. Is it merely to get a set of independent tests, each measuring something different? If so, what is the value of explaining the results of a given number of actual tests in terms of a larger number of imaginary ones? And why should we choose common factors that explain as little as possible of the observed results, which is what is done by minimising the communalities? These are the questions he will ask himself; and as they are the questions about which most arguments among factor analysts and statisticians revolve it would be difficult to deal with them shortly. It might, however, be worth giving explicitly the basic assumption, that a subject's score on a test can be regarded as the weighted sum of his scores on a set of other tests, each measuring something different and therefore not correlated with each other. Such tests do not exist but, if the assumption be accepted, a suitable set can be deduced from the observed correlations. The size of this set will be determined to a large extent by the values of the communalities, that is, by how far we can regard the existing tests as already measuring independent effects. For the use of factors in scientific explanation the reader might be referred to Braithwaite, and, for some notion of the disputes about meaning and methods, to the discussion following Kendall's and Babington Smith's papers to the Royal Statistical Society.

The budding geometer, to whom this book is also commended in the Preface, may complain that it is incomplete for another reason. He will see no connection between the r occurring in the equation of an ellipse and the r defined as a product-moment correlation (page 9) and, in fact, this requires a knowledge of the bivariate normal distribution and of the method of estimating the constants occurring in its equation. He will surely see no reason why selection on a test should cause a plane to move at right angles to itself (page 15). It would help such a reader to be given also the model used by statisticians in dealing with multivariate data. In this, the N subjects are represented by N orthogonal axes in N dimensions. A subject's scores on the various tests are represented by distances measured from the origin along his own axis. Then all the subjects scores on one test will fix a point in the space and the line joining this point to the origin is a vector representing the test. Two such tests will define a plane through the origin and n of them will define an n-dimensional space. The cosine of the angle between two tests will equal their product-moment correlation, as can be seen by using section Five. This model will, in the end, be similar to Thomson's, but it has the advantage of giving a simple definition of r, and the result of selection, that is the removal of some of the axes, can easily be seen by simple geometry to give the results of Section Two. The main problem is then to replace these n vectors by n or more that are right angles to each other. To be familiar with such a model is valuable not only to the young geometer but also to anyone interested in current methods of multivariate analysis.

This is not a book that, on its own, is of much value to the general psychologist. Read in conjunction with some other text book on factor analysis, say the author's own earlier book *Factorial Analysis of Human Ability*, it would help to give a simple geometrical picture of the processes involved in the extraction of factors. It would be very much improved by a short bibliography.

V. R. C.

Method and Theory in Experimental Psychology, By Charles E. Osgood, London, Geoffrey Cumberlege. Oxford University Press, 1953. Pp. vii + 800. 80s.

This book though lengthy is valuable. If Professor Osgood has not had time to be brief he has found time to digest much of the recent experimental literature in American psychology, and by deliberate selection he has succeeded in presenting the individual endeavours of innumerable experimenters as a continuous story with a plot made up of a few major theoretical issues.

The division of material is traditional. There are four parts, Sensory Processes, Pp. 1–189; Perceptual Processes, Pp. 191–297; Learning, Pp. 299–599; and Symbolic Processes, Pp. 601–727. The writer's intention, as stated in his preface is to provide "a text that evaluates experimental literature in close relation to critical theoretical issues." Though there may be reservations about Osgood's selection of "critical theoretical issues" he has succeeded in his efforts to link experimental facts to theory, whilst still providing "a more detailed description of critical experiments" than is usually given. The excellent accounts and comments on experiments, supplemented by diagrams, are a feature of the book and there is no doubt that with it in his possession many a student will now contentedly leave original papers to dust on the library shelves.

On so many of the issues which he raises Osgood is eminently sound—on the psychophysical methods, his chapters on retention or on neurophysiology and learning where traditional terms such as equipotential, vicarious functioning etc. are discussed with an untraditional clarity. He is at his best where he is extending his own Statistical Theory of Figural After-Effects to cover movement perception and binocular fusion, or in his chapter on "Serial and Transfer Phenomena" relating the hoary problems of the similarity paradox and retroactive inhibition to his own work.

In such sections there is much to stimulate the thoughtful reader—it is as a contribution to Method and Theory in Experimental Psychology that the book is disappointing. Osgood writes much about theories but little about theory; his book illustrates many but it never clarifies the standpoint from which it judges one. Osgood himself favours an intermediate position—he makes the best of different schools, solving his problems by a better use of the tools which others have left lying around. It is his role to resolve the theoretical issues, say, between Gestalt and Behaviouristic psychology, and he puts forward his mediation hypothesis to provide a consistent account of adaptive behaviour which he observes has affinities with Hull, Tolman and Guthrie. It is commendable that such a reconciliation obviously inspires him, "We seem to be approaching a point where they (major learning theories) can be viewed within a consistent frame of reference" (p. 410). The student who has acquired a working knowledge of current American theory will be refreshed by Osgood's matter-of-fact comments on these issues. But in a book under this title one might have expected more appreciation of the different types of theory which do exist in present-day psychology. Osgood may be trying to reconcile the irreconcilable though he gives no hint that there are different kinds of theory. Yet under the title of theory psychologists are accustomed to find for example mere restatements of the problem in a descriptive phraseology, speculations about the operation of the nervous system, and logically inter-related models attempting to explain the workings of a system. If the different authors have not always been precise as to what they were attempting it is the task of a text which deals so exhaustively with the individual theories to be clear on this issue.

Closely related to this defect is another. Just as Osgood never hints that a different kind of theory might be possible, so too he is content to deal exclusively with the problems of psychology as defined by his contemporaries. It is not the point that a book by a single author is not all-embracing, but that significant trends are ignored. Gibson's work (1951) is ignored presumably because of the time interval between writing and publication, and perhaps the same excuse might be advanced for the uncritical acceptance of Senden's evidence and Riesen's experiments as supporting perceptual learning with no mention of the objections which largely vitiate this conclusion. But if such a book can afford to omit recent work on the study of skills it would seem ill advised to ignore the studies of comparative ethologists—here there are some traditional methods being effectively employed and a theory in an interim stage of development with important implications for the study of motivation.

However it is stressed that these criticisms are put forward only on the assumption that Osgood has written a first-class text book. It is an excellent appraisal of psychological experiments, both old and new, it has original contributions to make in several fields and is unusually sound in many others. And if it is not a classic of English prose, at least the jargon of the seminar is diluted with that of the sidewalk. As it will be widely read, another edition might take the opportunity to rectify some of the typographical errors—for example the careful reader will be unable to find any ellipses in Figure 77C, p. 214, will be puzzled by the last sentence on p. 521, will find the second reference to Figure 177 on p. 538 should be to Figure 176, and be confronted by an ordinal series of 1, 2, 4 on p. 519.

H. K.

INDEX OF AUTHORS

Page

BERLYNE, D. E., with Gordon, W. M.
Drive-Level and Flexibility in Paired-Associate Nonsense-Syllable Learning - - - - - - - - - - - - 181

BROADBENT, D. E.
Some Effects of Noise on Visual Performance - - - - - - 1

BROWN, J.
The Nature of Set-to-Learn and of Intra-Material Interference in Immediate Memory - - - - - - - - - - 141

DEUTSCH, J. A.
A Machine with Insight - - - - - - - - - - - 6

EARLE, A. E., with Hall, K. R. L.
A Further Study of the Pendulum Phenomenon - - - - - - 112

GLYNN, A. J.
Apparent Transparency and the Tunnel Effect - - - - - - 125

GORDON, W. M., with Berlyne, D. E.
Drive-Level and Flexibility in Paired-Associate Nonsense-Syllable Learning - - - - - - - - - - - - 181

HALL, K. R. L., with Earle, A. E.
A Further Study of the Pendulum Phenomenon - - - - - - 112

HOWARTH, C. I.
Strength Duration Curves for Electrical Stimulation of the Human Eye - 47

HUNTER, I. M. L.
Tactile-Kinaesthetic Perception of Straightness in Blind and Sighted Humans - - - - - - - - - - - - - 149

HURWITZ, H. M. B.
Response Duration of Lever Pressing in the Rat - - - - - - 62

JACKSON, C. V.
The Influence of Previous Movement and Posture on Subsequent Posture 72

JONES, L. C. T.
Frustration and Sterotyped Behaviour in Human Subjects - - - - 12

KAY, H.
The Effect of Position in a Display upon Problem Solving - - - 155

KELVIN, R. P.
Discrimination of Size by Sight and Touch - - - - - - - 23

LANER, S.
The Impact of Visual Aid Displays Showing a Manipulative Task - 95

LEONARD, J. A.
An Experiment with Occasional False Information - - - - - 79

Page

MOWBRAY, G. H.

The Perception of Short Phrases Presented Simultaneously for Visual and Auditory Reception - - - - - - - - - - - 86

NEWSON, L. J.

A Projection Tachistoscope - - - - - - - - - - - 93

REID, R. L.

An Illusion of Movement Complementary to the Horizontal-Vertical Illusion - - - - - - - - - - - - - - 107

STEINBERG, H.

Selective Effects of an Anaesthetic Drug on Cognitive Behaviour - - 170

SUTHERLAND, N. S.

Figural After-Effects, Retinal Size, and Apparent Size - - - - - 35

WERTHEIMER, M.

Can a Trained Subject Judge his Auditory Sensitivity? - - - 21

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